BNL - CERN- FNAL - LBNL - SLAC

LARP

LARP BEAM INSTRUMENTATION

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Presented at the DoE review of LARP

SLAC

Jul. 9-10, 2012

Outline

Overview of LARP instrumentation

Experience from beam commissioning and operations

- Sync Light Monitor
- Lumi – IP optimization

LTV/Toohig Impact

Conclusions and Outlook

Overview of LARP Instrumentation

LARP

Since the beginning of LARP, the instrumentation program has been making significant contributions to the LHC:

- AC Dipole
  - Due to the LHC's slow cycle (~1 hr for ramp up, ramp down, squeeze, precycle…), the AC dipole (non destructive) is **the only probe to beam optics above injection** energy
  - ***β*-beating and local coupling** have been measured and corrected for β-squeeze with the AC dipole
- Synchrotron light monitors
  - Actively the main **abort gap monitor**
- Schottky monitors
  - Increasing presence: beam-beam, chromaticity measurements
- Luminosity monitors
  - Now the only instrument to measure collision rate to **optimize IP**
- Tune tracker
  - Essential element during the **ramps**

Advancing Accelerator Technology

LARP

Major contributions to the field:

Benefiting the LHC and US colliders

- The AC dipole concept came from LARPs collaborations

  now installed in all three hadron colliders

- The luminosity Monitor is designed to survive a level of radiation 100x larger than ever seen before

- Synch light monitoring on proton storage ring – world first – from PEPII experience to light from Pb ions!

- Tune and Coupling feedback is a world first, accomplished in RHIC

- The LHC Schottky monitor lead to the upgrade of the Tevatron system

Graduate students and post-docs actively involved

- 1 PhD on AC Dipole, then Toohig fellow
- 1 Graduate student in Lumi
- Several student projects in Lumi
  - Best project award at Sep 2009 APS-CA meeting

Current Focus of LARP Instrumentation

- Synch Light monitor
  - Expanding into abort gap monitor + ghost/satellite bunches
  - Developing beam halo monitor
  - Developing fast bunch-by-bunch beam size monitor
- Lumi monitor
  - Developing analysis tools
  - Improving operational tools
  - Completing FLUKA model and preparing for asymmetric collisions
- Possible new activities

Synchrotron-Light Monitors

Two applications:

- BSRT: Imaging telescope, for transverse beam profiles
- BSRA: Abort-gap monitor, to verify that the gap is empty
  - When the kicker fires, particles in the gap get a partial kick and might cause a quench.

Two particle types:

- Protons and lead ions

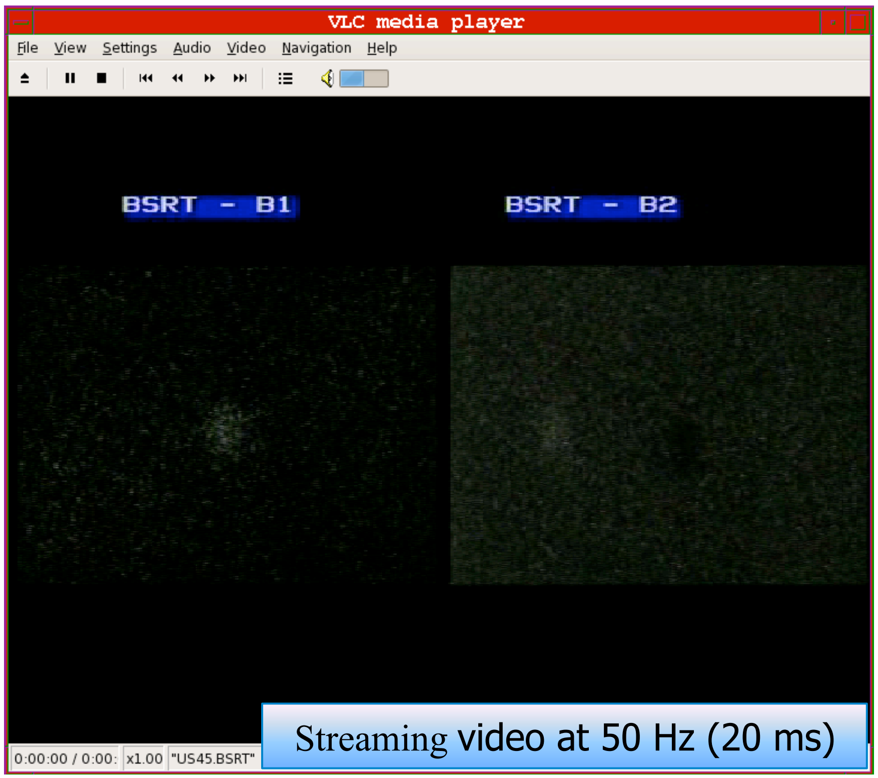
Three light sources:

- Undulator radiation at injection (0.45 to 1.2 TeV)
- Dipole edge radiation at intermediate energy (1.2 to 3 TeV)
- Central dipole radiation at collision energy (3 to 7 TeV)
- Spectrum and focus change during ramp

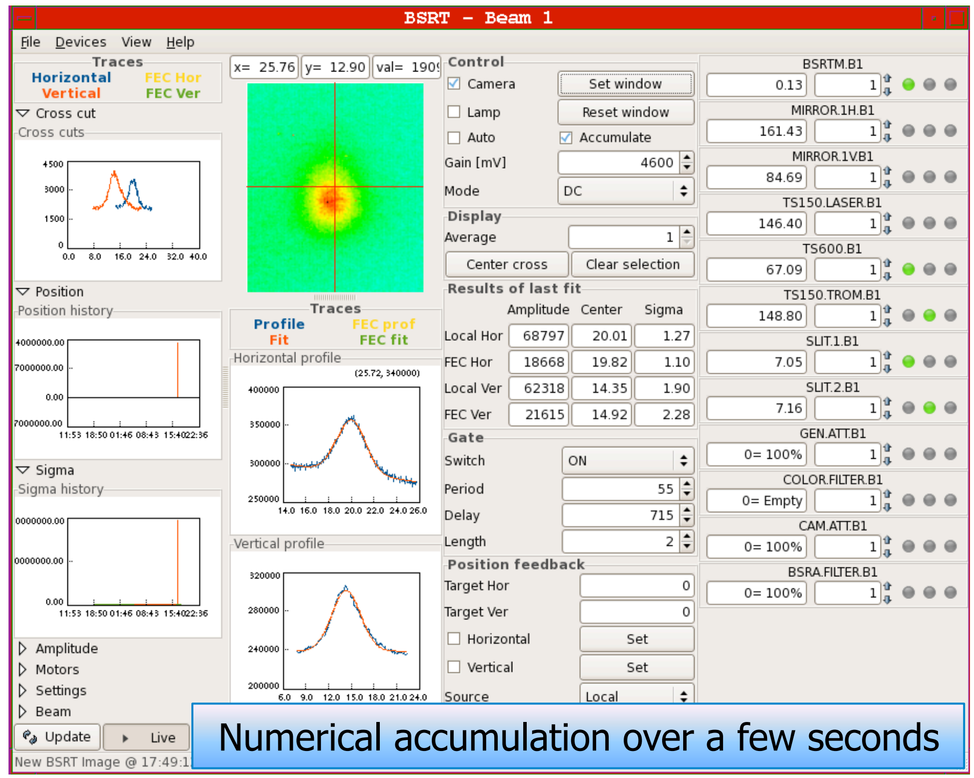
A. Fisher-SLAC

First Images of Lead Ions at Injection

- 2010 Nov 10: Light from 17 bunches, integrated over 20 ms
- Images are faint, since most emission is infrared at this energy
  - Original prediction: 1-s integration needed for a clear image of a single bunch
    - Equivalent to 20-ms integration of 50 bunches
    - 1-s integration directly on the CCD would require only an additional logic pulse



Streaming video at 50 Hz (20 ms)



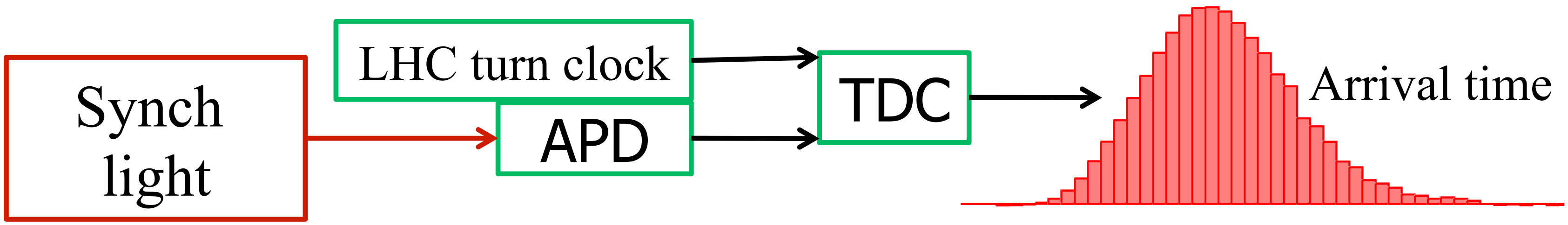
Numerical accumulation over a few seconds

Longitudinal-Density Monitor

Proposed by LBL in the initial LARP proposal – eventually not funded by LARP

Monitor built by Adam Jeff (CERN)

- Photon counting using an avalanche photodiode (APD)
- 1% of the BSRT's synchrotron light
- Histogram of time from turn clock to APD pulse, with 50-ps bins

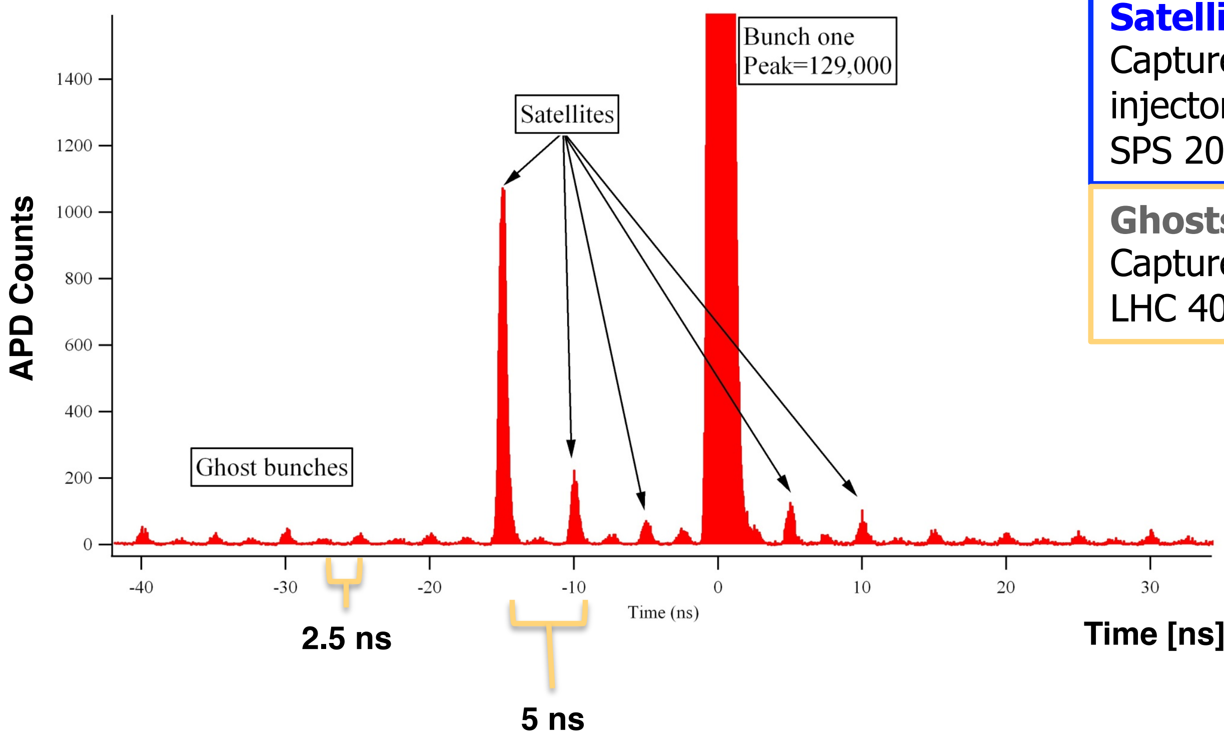


Modes:

- Fast mode: 1-ms accumulation, for bunch length, shape, and density
  - Requires corrections for photon pile-up, APD deadtime and afterpulsing
- Slow mode: 10-s accumulation, for tails and ghost bunches down to 5×10^5 protons (4×10^{-6} of a nominal full bunch)
  - Only 1 photon every 200 turns

LDM Measurement

Ions with 10-min integration



Satellites
Capture/splitting errors in the injectors
SPS 200 MHz → 5 ns

Ghosts
Capture/splitting errors in the LHC
LHC 400 MHz → 2.5 ns

LDM is the only LHC system able to see all structures from RF, with enough **dynamic range** and **time resolution** for monitoring satellites and ghosts

Recognized at Lumi days for its help with lumi calibration

Continuing Synch Light Monitor Development

LARP

Beam-Halo Monitor

- Measures beam halo and shows the effect of a change in collimation
- Collaborators:
  - SLAC: Jeff Corbett
  - University of Maryland (College Park, MD):
    Ralph Fiorito, Anatoly Shkvarunets, Hao Zhang

Fast Bunch-by-Bunch Beam-Size Monitor

- Measures RMS size of every bunch at 1 Hz
- Collaborators:
  - SLAC: Jeff Corbett
  - University of Victoria (Victoria, BC, Canada): Justin Albert

Beam-Halo Monitor

LARP

Halo monitoring was part of the original specification for the synchrotron-light monitor.

- LARP's involvement in both light monitors and collimation makes this a natural extension to the SLM project.
- Challenging dynamic range

But the coronagraph needs some changes:

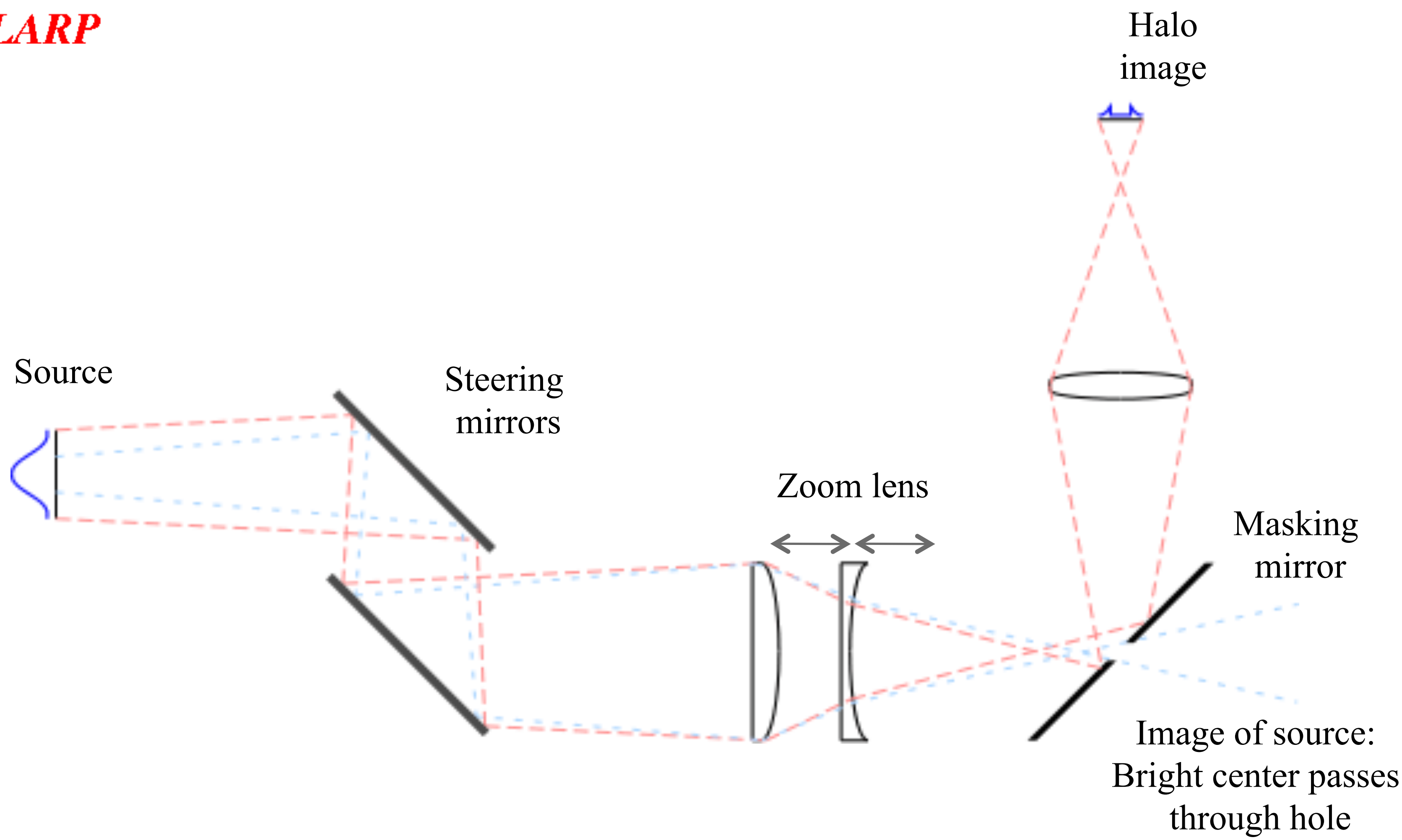
- The Sun has a constant diameter and a sharp edge.
- The beam has a varying diameter and a profile that is roughly Gaussian

An adjustable mask is needed. Two approaches:

- A Digital Micro Mirror Array
- Rotating Mask

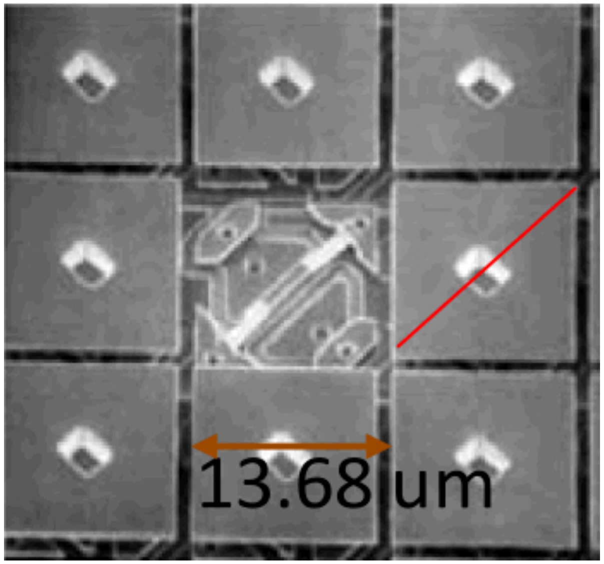
Testing these possible upgrades at SLAC's SPEAR-3.

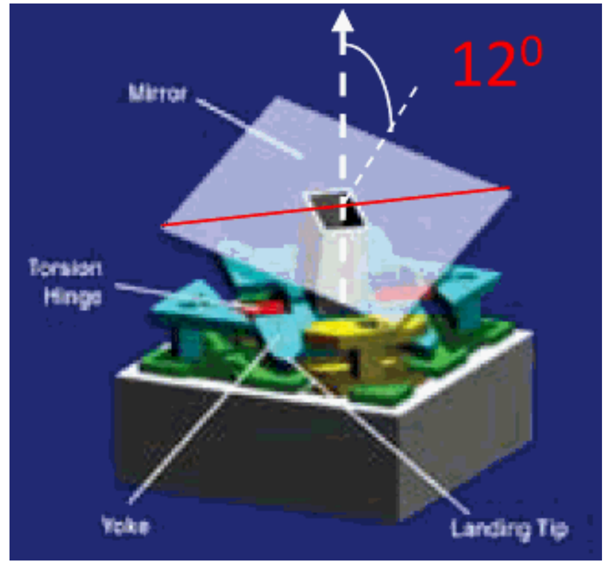
Fixed Mask with Zoom Optics



Digital Micro-Mirror Device (DMD)

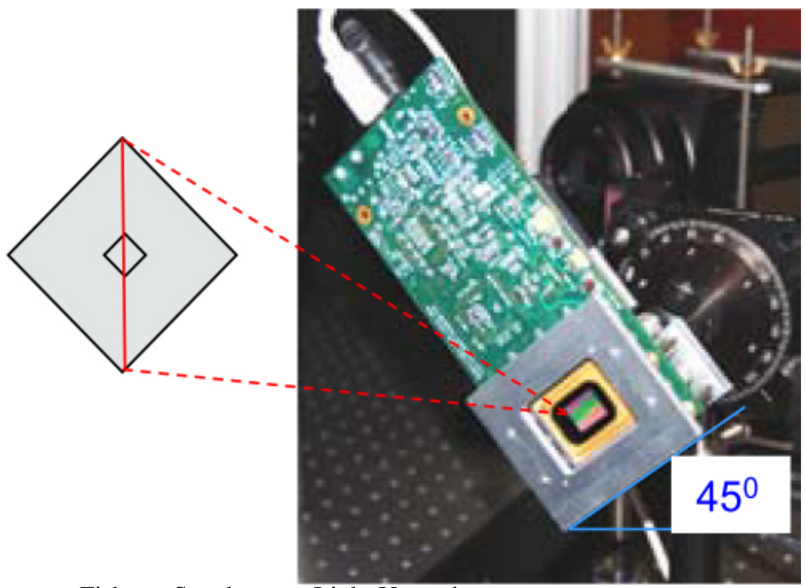
1024 × 768 grid of 13.68-µm square pixels



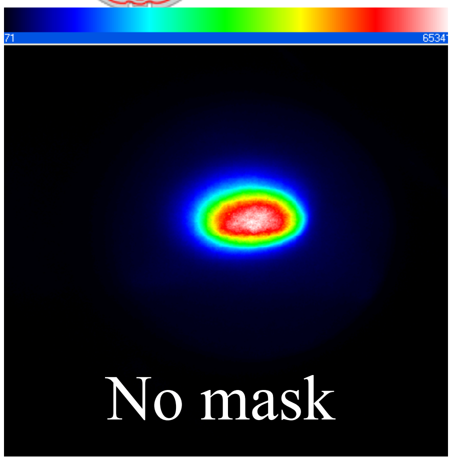


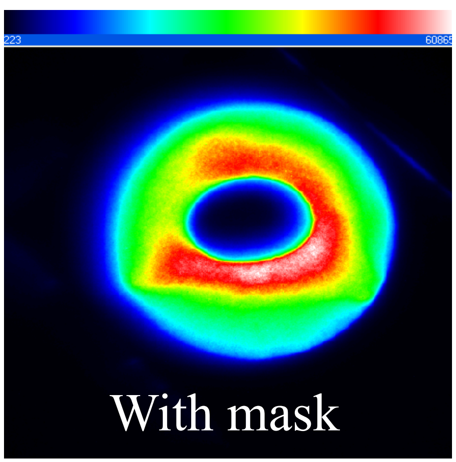
Pixel tilts about the diagonal, toggling from −12° to +12°

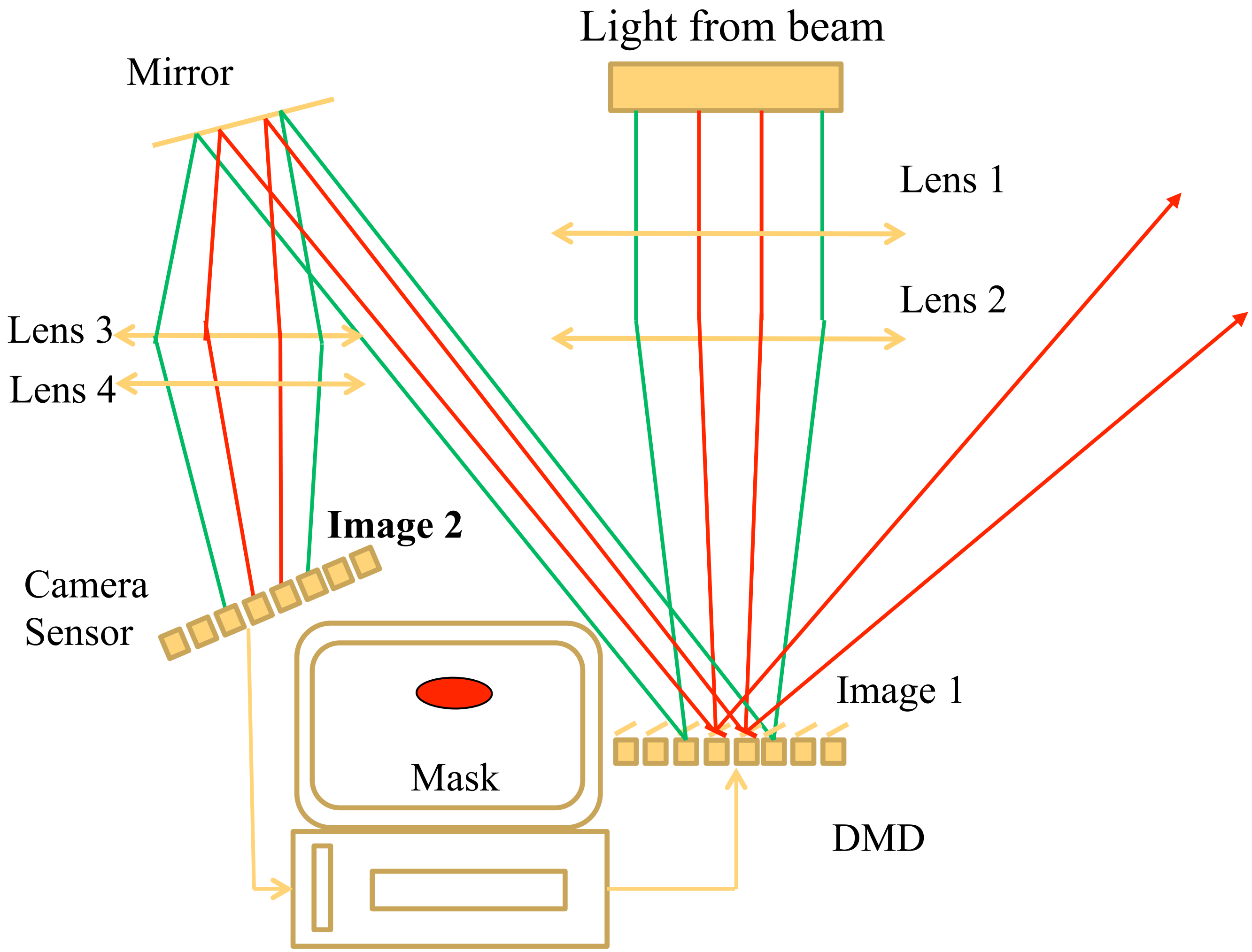
Mirror array mounted on a control board, which is tilted by 45° so that the reflections are horizontal.



High Dynamic-Range Imaging with a DMD







R. Fiorito, H. Zhang *et al.* (University of Maryland), Proc. BIW2010

DMD: Advantages & Disadvantages

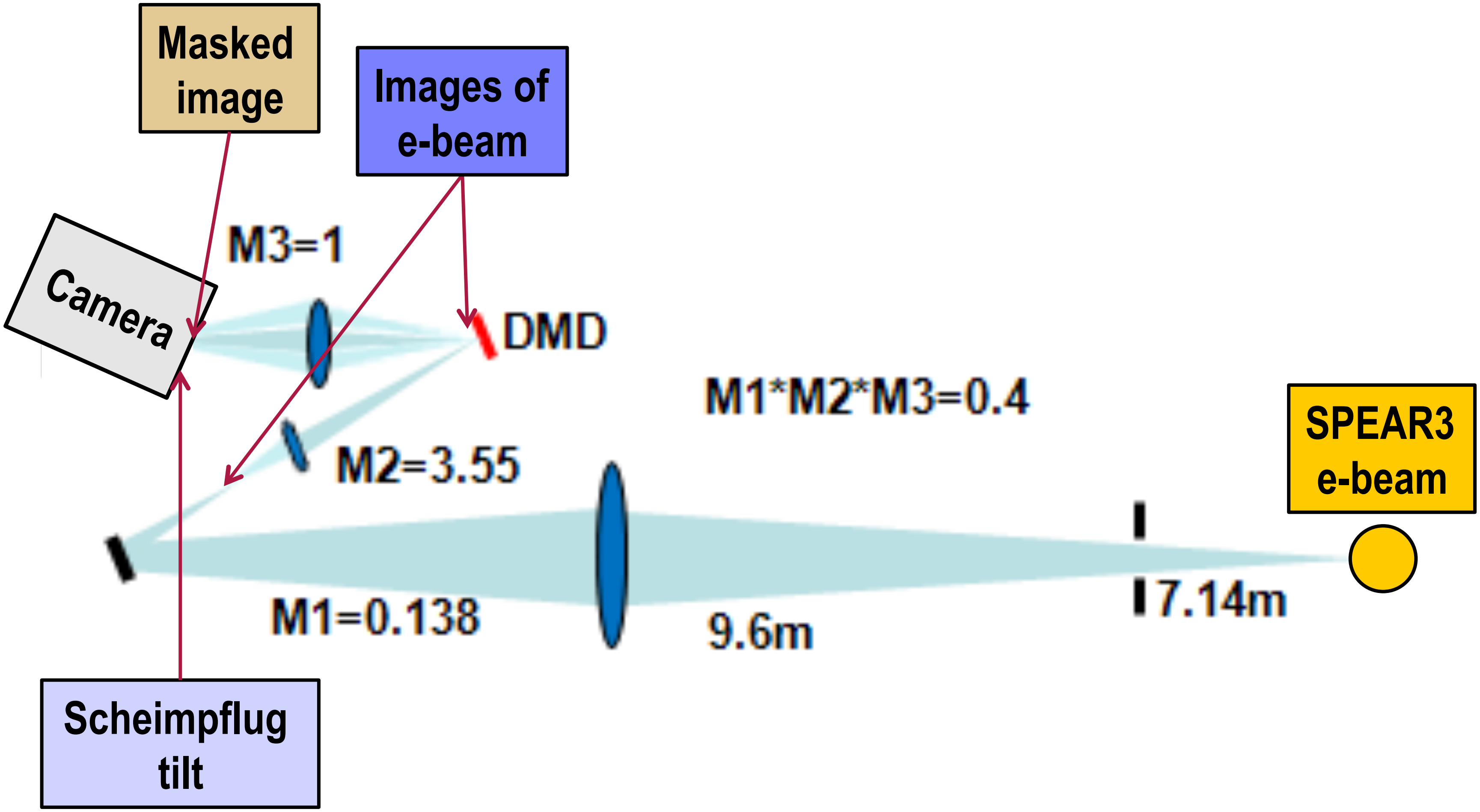
Advantages of DMD:

- Masking is very flexible due to individually addressable pixels

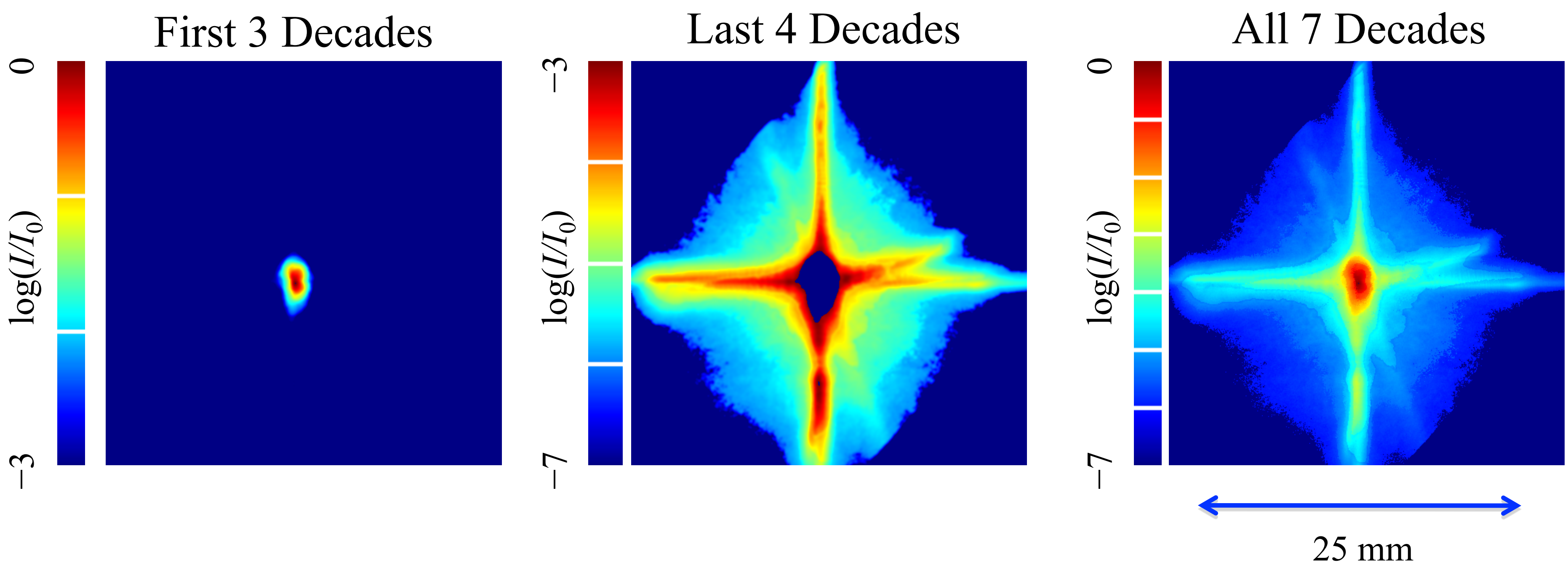
Disadvantages of DMD:

- The pixels are somewhat large for the LHC
  - RMS size: 14 pixels at 450 GeV, but only 3.4 pixels at 7 TeV
    - Large distance from source to first focusing mirror demagnifies intermediate image by a factor of 7
  - Some improvement with a newer DMD for HDTV, with 10.8-μm pixels
    - RMS beam size is 4.3 pixels at 7 TeV
- Beam is imaged onto tilted pixels of DMD plane: Virtual source plane for camera is not perpendicular to optical axis
  - DMD has features of a mirror and a grating
  - Fixed by tilting camera face for best focus across the image plane
    - Known as Scheimpflug compensation

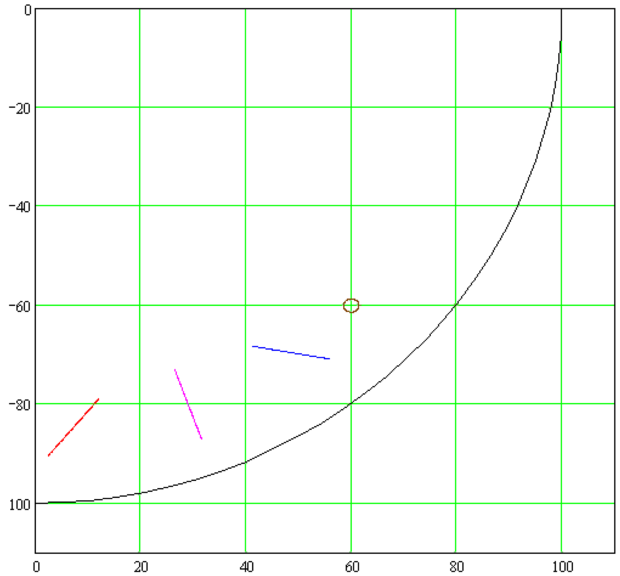
DMD Optics on SPEAR3 at SLAC

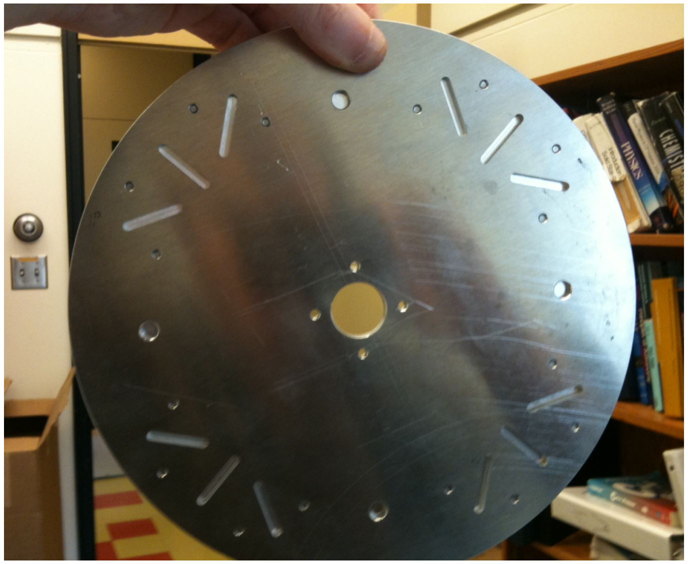


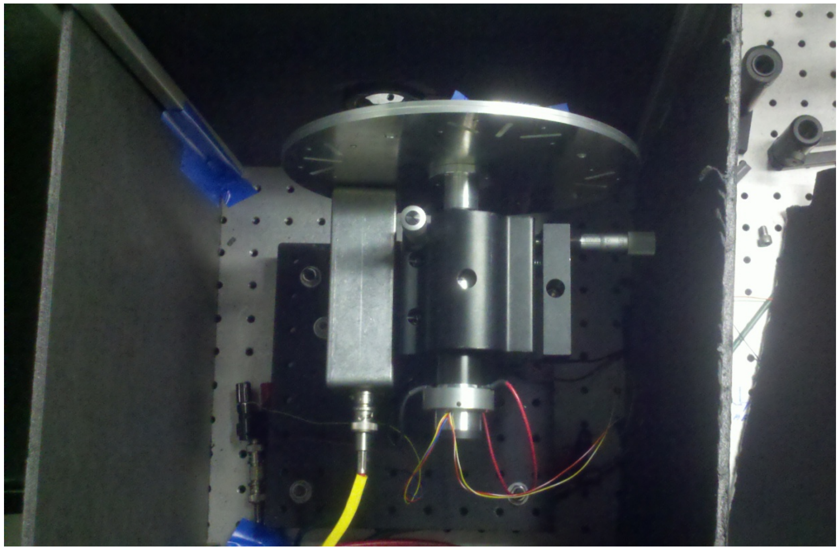
Composite Images, Logarithmic Scales



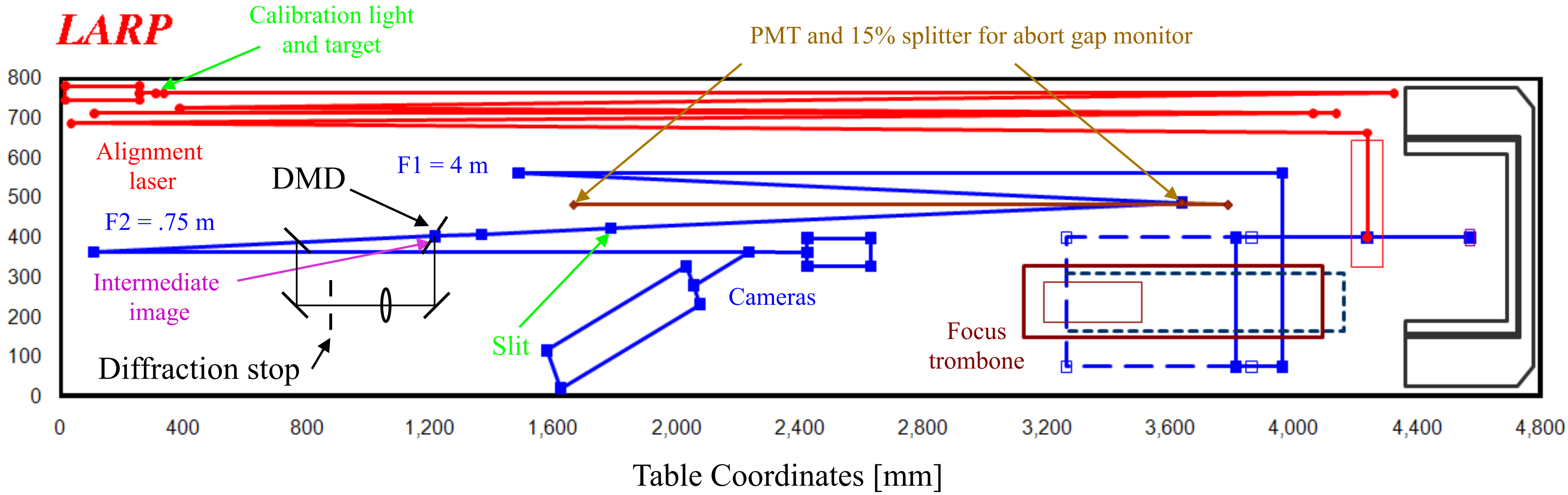
Mask Rotating across Beam







Adding a Halo Monitor to the LHC Optics



During halo measurements:

- Insert DMD at intermediate image
- Return to main path with focus or path-length correction
- Rotate camera by Scheimpflug angle

This layout is simplified for illustration. In actual implementation:

- Path might go upward from DMD and return to camera at Scheimpflug angle
- Or DMD might be used for all measurements, occasionally masking center
- Or use DMD to split core and halo light, and add a camera to image the halo

Synch Light Development Summary

LARP

Two possible additions were tested on the SPEAR3 electron ring at SLAC

Beam-halo monitor using a digital micro-mirror device

- Dynamic range of 10^7 for the SPEAR optical system
- The LHC optical design needs to be modified to add a DMD
- Measure the point-spread function and dynamic range on the test bench at CERN

Rotating-mask bunch profiler

- Designed to measure the RMS size of each LHC bunch at 1 Hz
- Fast profiling demonstrated at SPEAR
- Needs to be tested further with more uniform slits
    - Micro-EDM may be a substantial improvement over laser cutting

Lumi Status

LARP

With 2011 shutdown, all forward (ZDC) detectors have been removed

- TANs are now configured for high luminosity operation
- Different configuration due to modified absorbers

Remains the only instrument available during MDs

- Regular shifts typically use the published experiments luminosity

Steady performance through 2011 and 2012

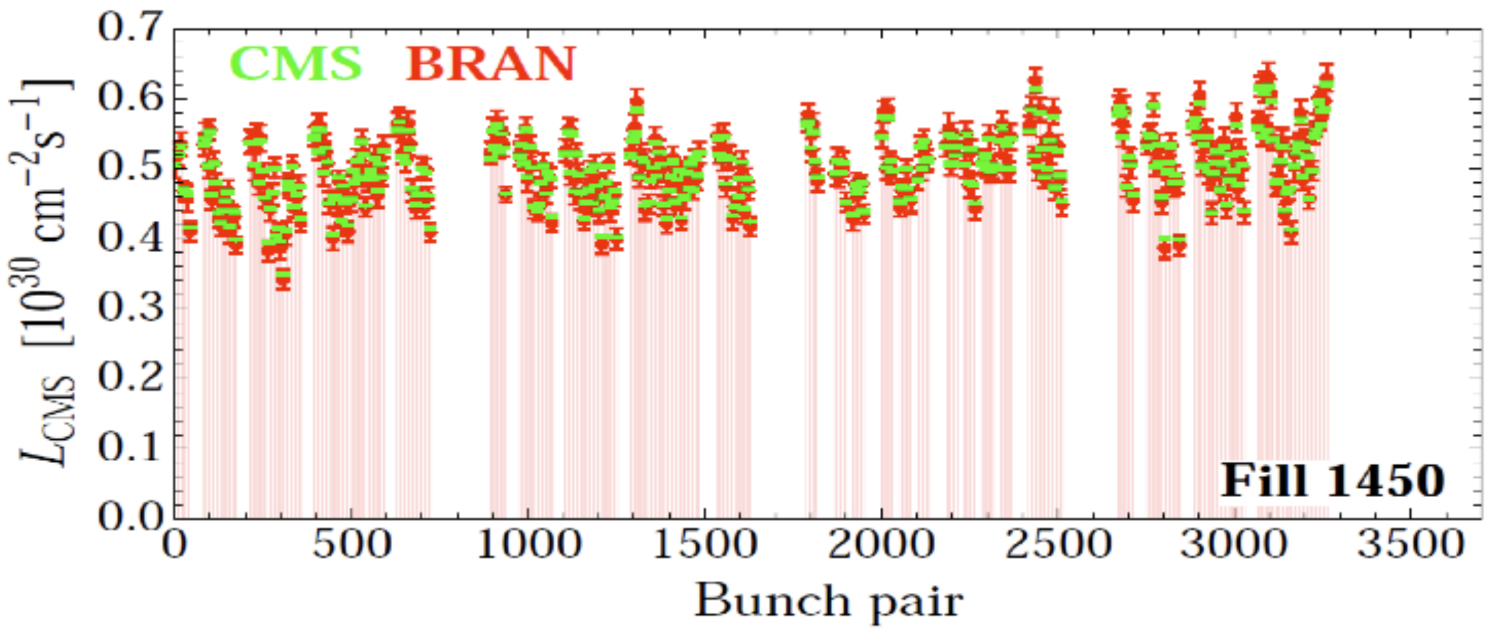
- One analog channel damaged

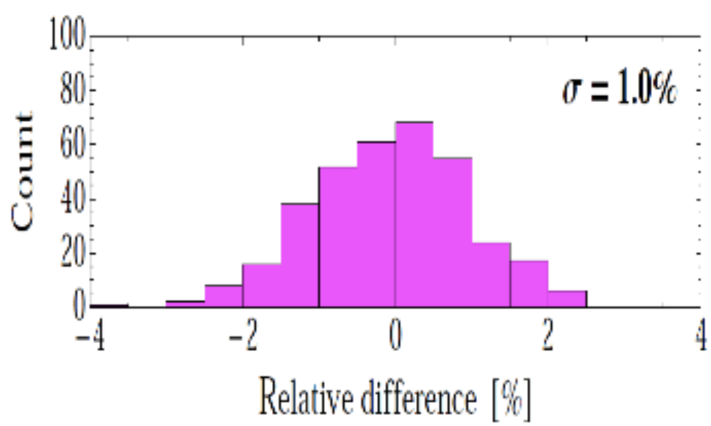
Need to adjust for ever improving luminosity

- Watch for peak bunch by bunch luminosity

LARP

Bunch-by-Bunch Luminosity





- ~1% discrepancy for bunch-by-bunch measurement.
- The discrepancy seems to come from the systematic.

Operator Interface and Application

Allows operators to monitor parameters in the system

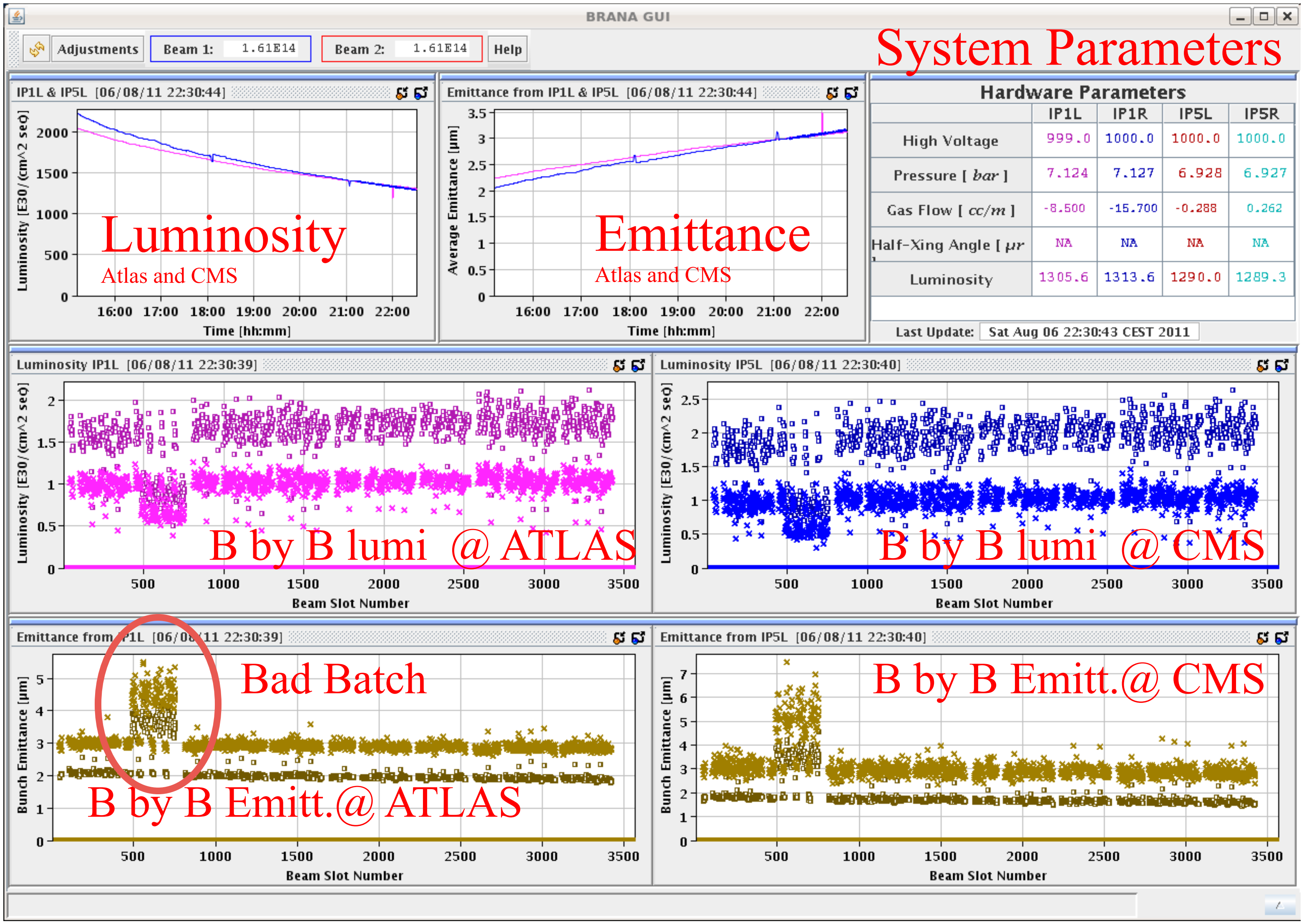
Plots bunch by bunch luminosity at both IPs

Calculates B-byB emittance from luminosity measurements

Allows user to save relevant data

Displays the operating parameters of the system

New GUI for use in the CCC



E. McCrory (FNAL), T. Lehay (SLAC)

LARP

Analog Configuration

As performance improves, we monitor for radiation damage and signal processing integrity

- Low levels of integrated dose so far
  - Only expect single event upsets, if any

Higher luminosity collisions could saturate the detector

- Electronics saturates much before ionization chamber

Starting to optimize readout chain – not as urgent for relative measurements

One pre-amplifier channel damaged in 2011

- not sure what caused the failure
- switched to spare channel during winter shutdown

Analog performance

Calibrated all analog quadrants with test pulse

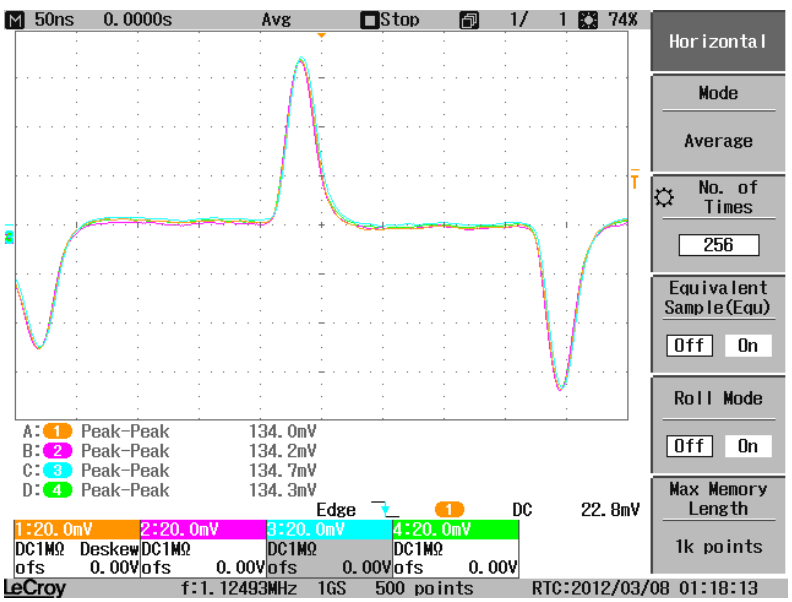
adjusted shapers gains and time constants

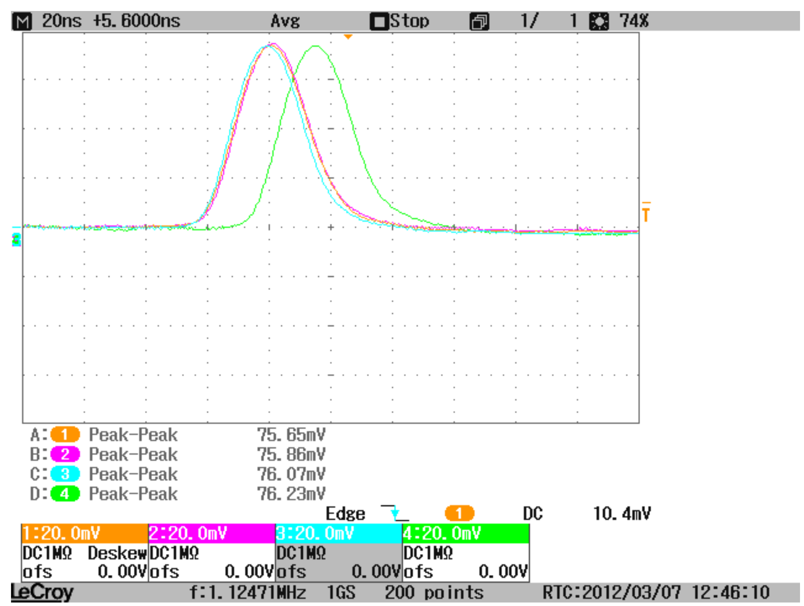
Time delays can be different due to different cable lengths

Can be corrected in the DAQ system

Different amplitudes between two sides of IP due to cable lenght

Biggest at Pt 5





Expert data acquisition tool

Timber records a limited set of data

- Counting mode @ left side, Pulse Height @ right of both IPs

Script by Enrico Bravin (CERN) allows to record simultaneously all detector parameters, bunch by bunch

Use to monitor performance of counting vs. PH

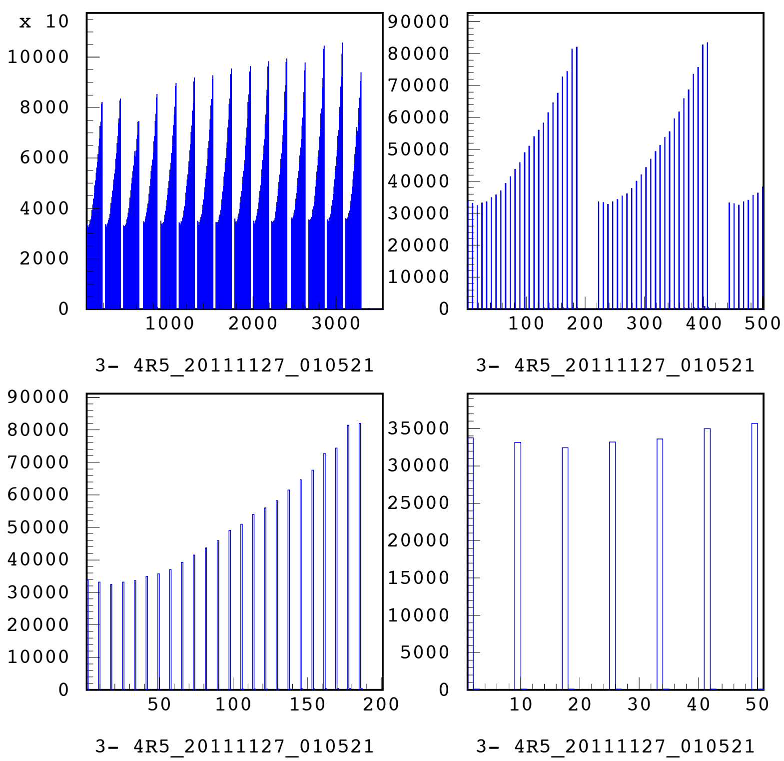
- and to calibrate and setup DAQ parameters for each channel

Allows also monitor background and noise levels

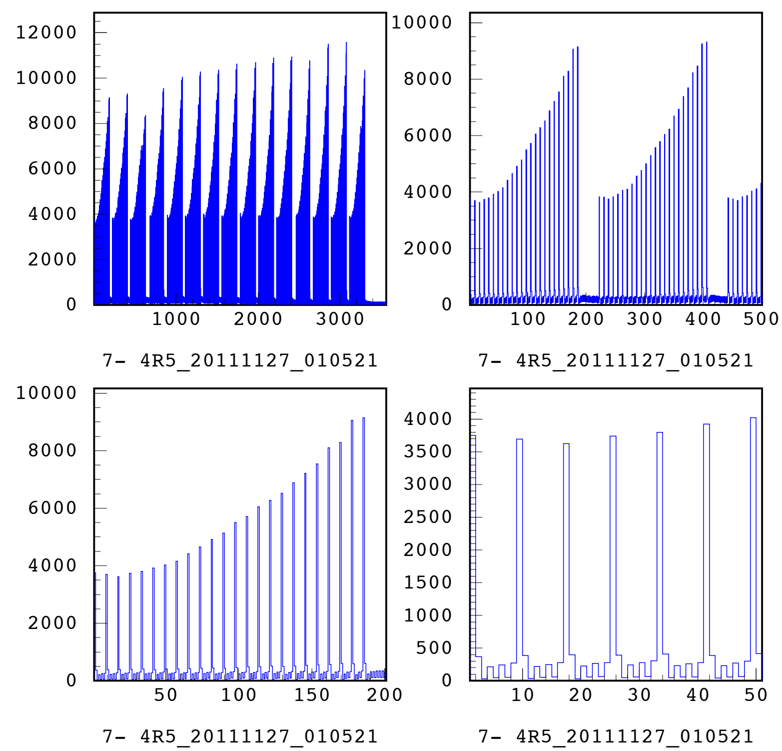
- Early indication of radiation damage

Signal Analysis

Counting Mode



Pulse Height Mode

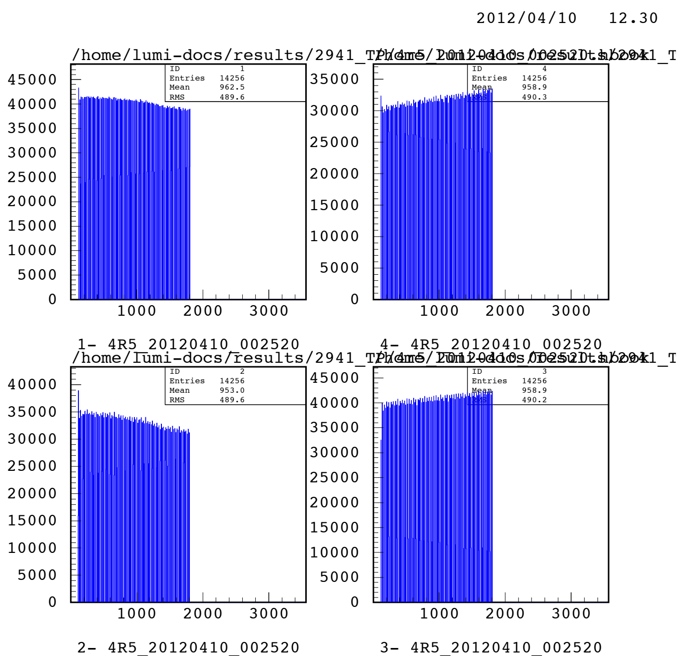


Data from Enrico’s script during the 2011 Pb-Pb run

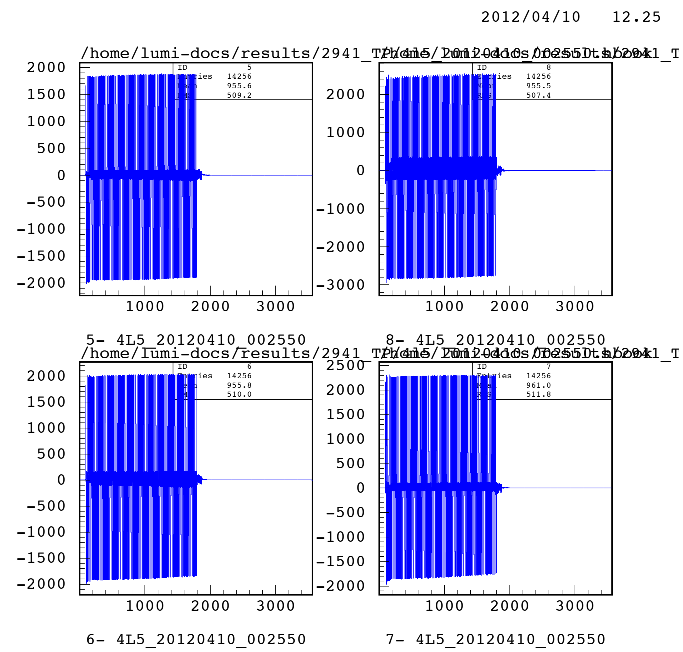
Performance measurements

LARP

Counting Mode

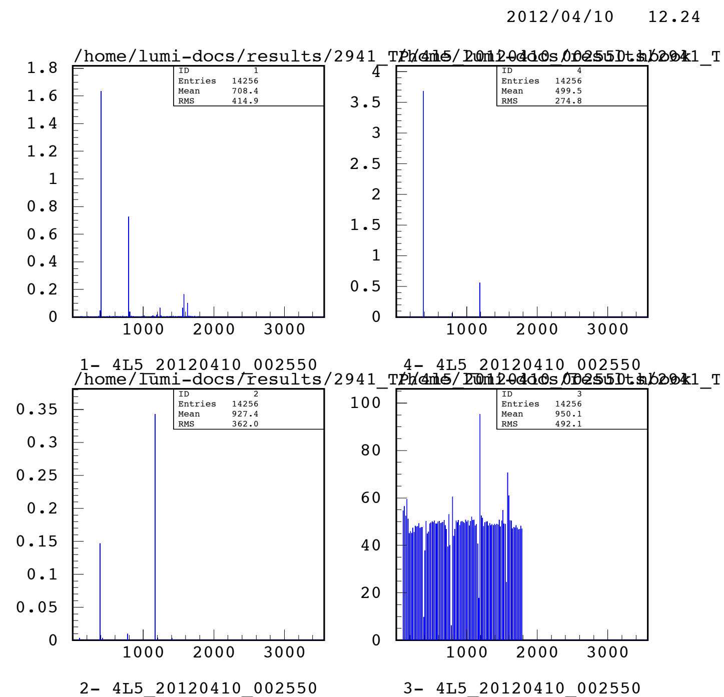


Pulse Height Mode



Pt 5 – response to an external calibration pulse

Misconfigured Counting Mode at 5L



Similar analysis allowed to identify damaged pre-amp

Calibration scans

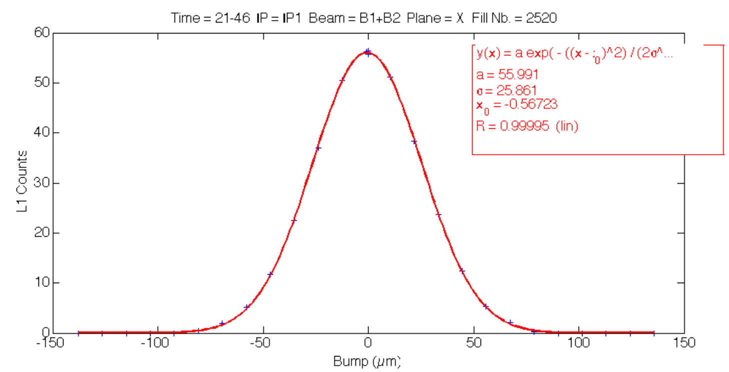
Van der Meer scans during dedicated MDs

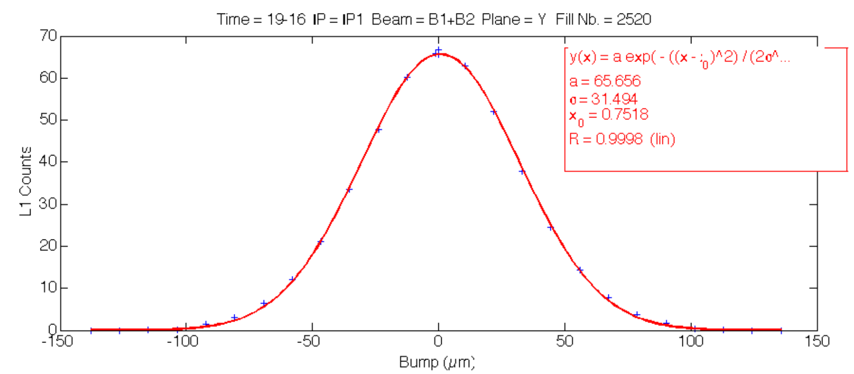
Experiments use them to calibrate internal luminosity algorithms

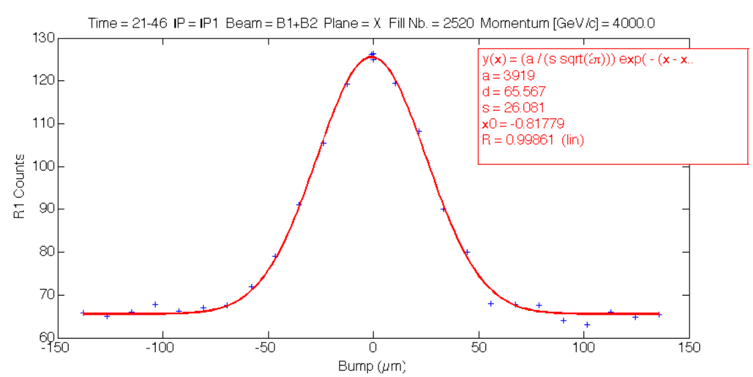
Data collected for all detectors, including BRAN

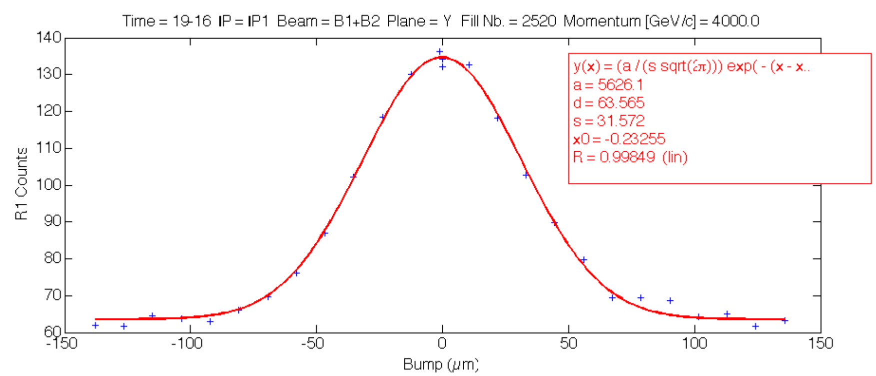
Can measure transverse dimensions of the beam at the IP

Scan results – IP1 X and Y







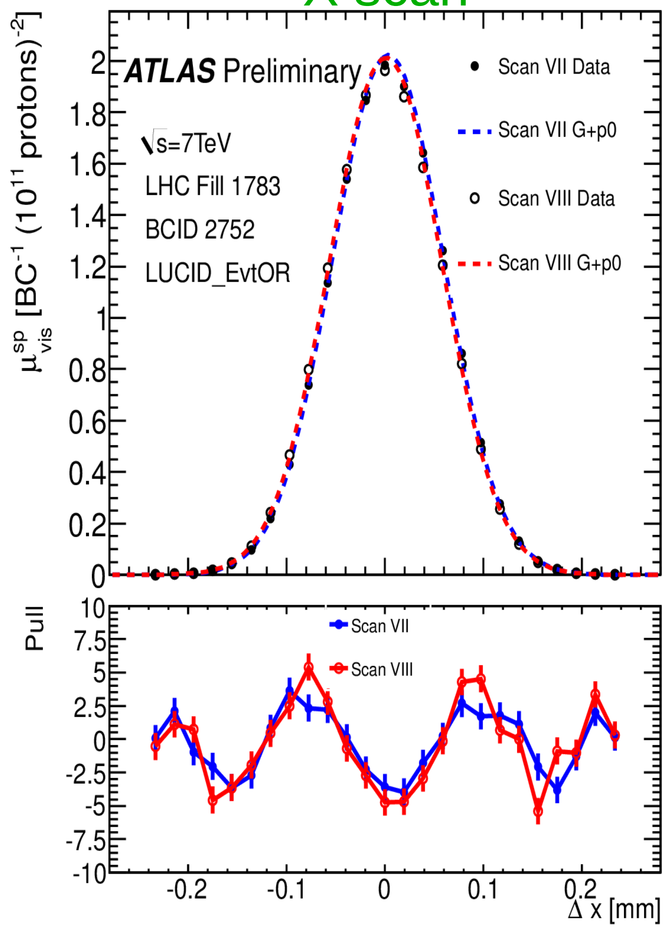


Pt 1 – offset to be studied

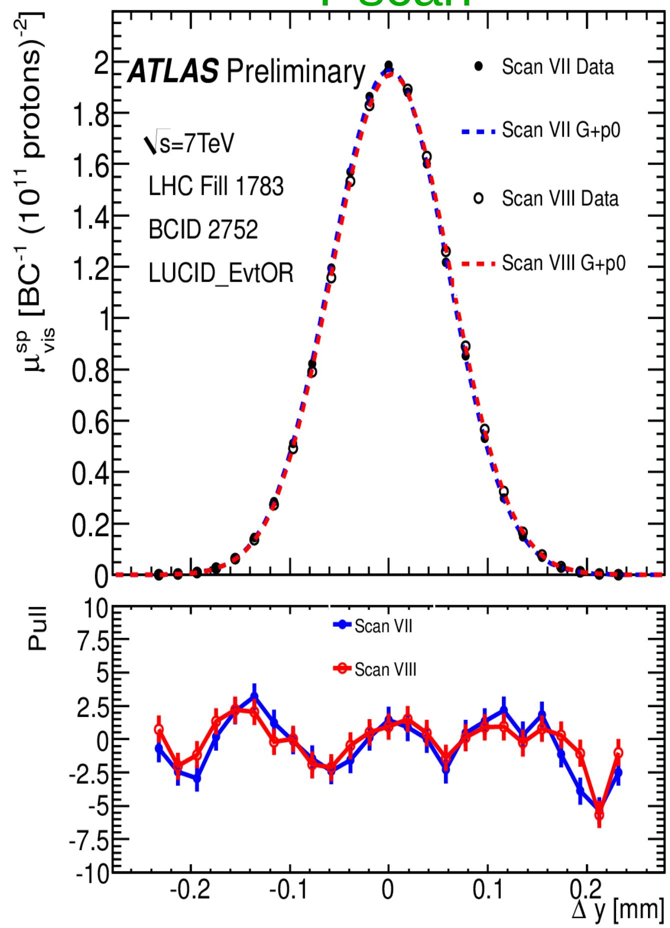
LARP

2011 scan results at ATLAS

X scan



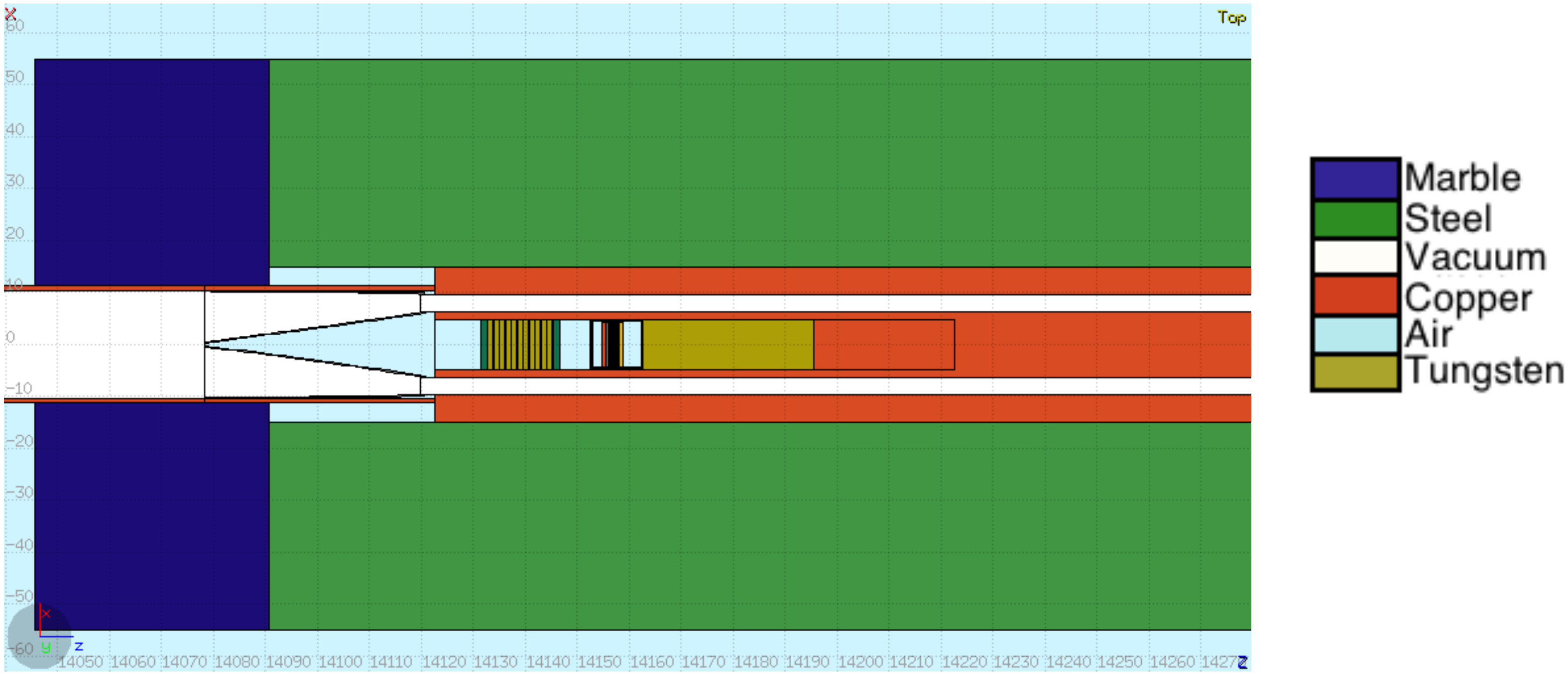
Y scan



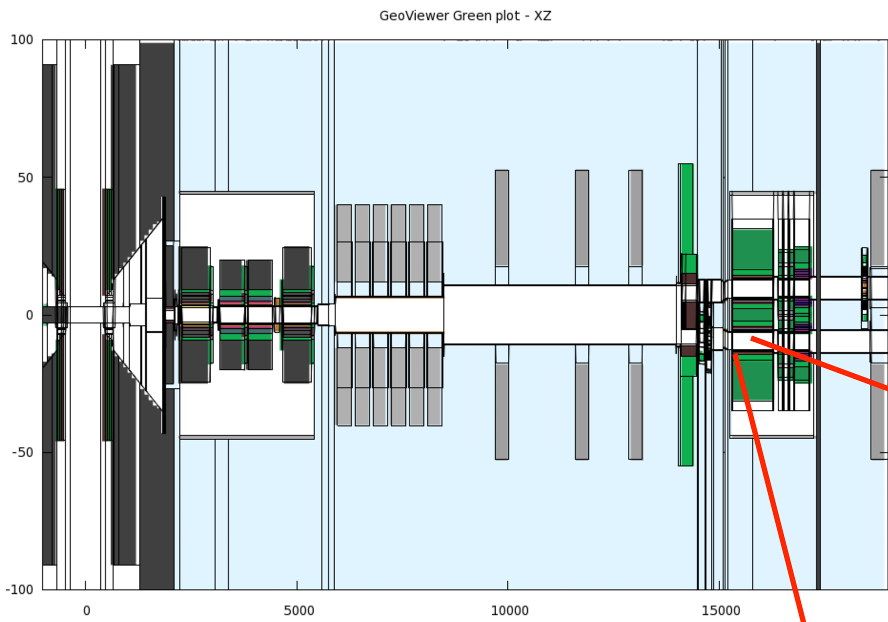
Overview of Simulations

Using FLUKA with IR1 and IR5 geometry implemented by CERN

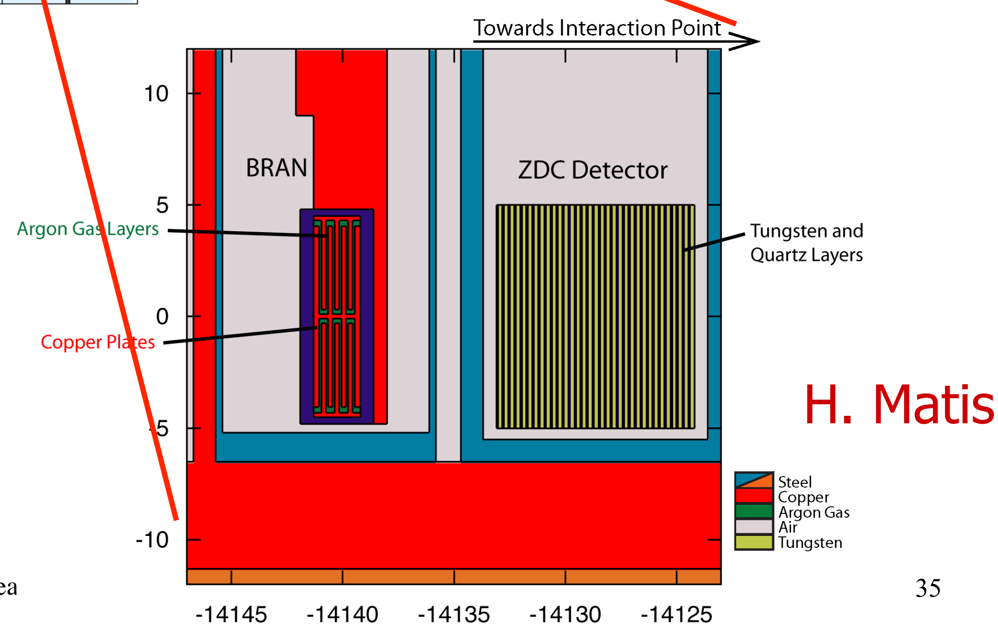
We have added a detailed model of the TAN including forward detectors and BRAN



FLUKA model of IP



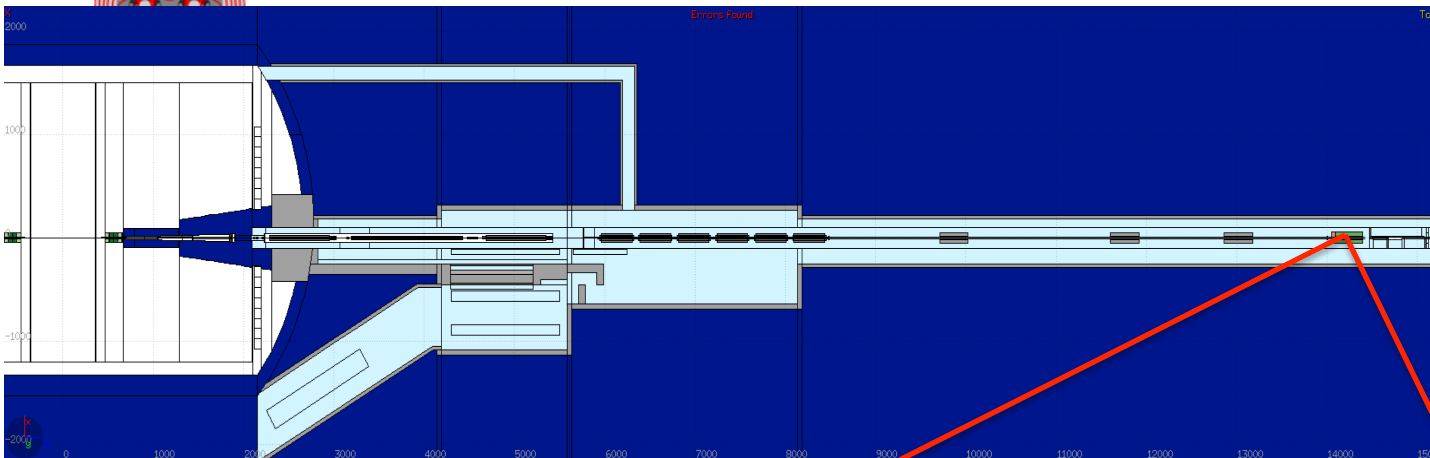
IP model developed at CERN



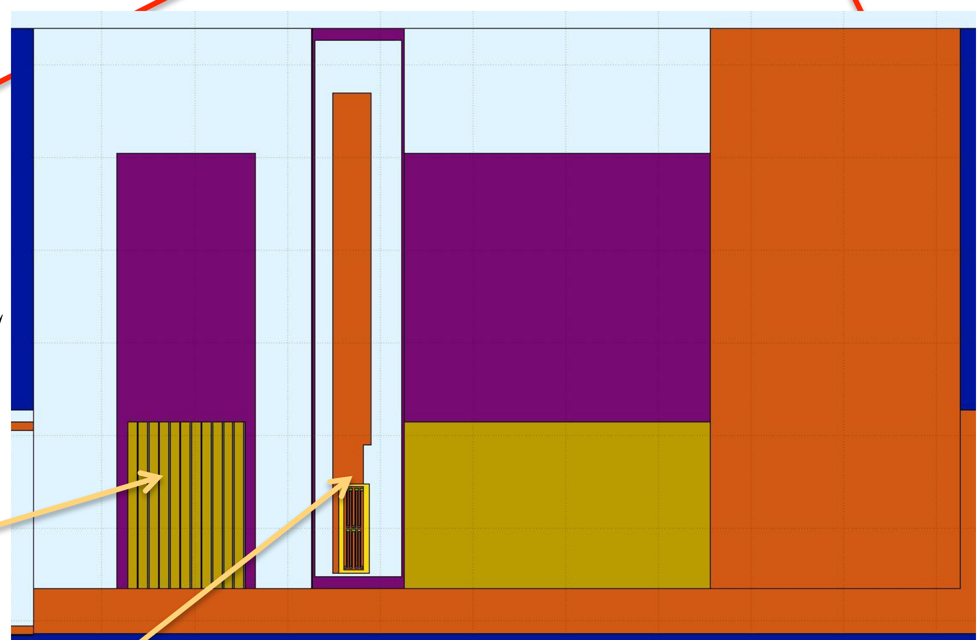
H. Matis

BRAN model previously developed at LBL

FLUKA model of ATLAS IP1



IP model developed at CERN

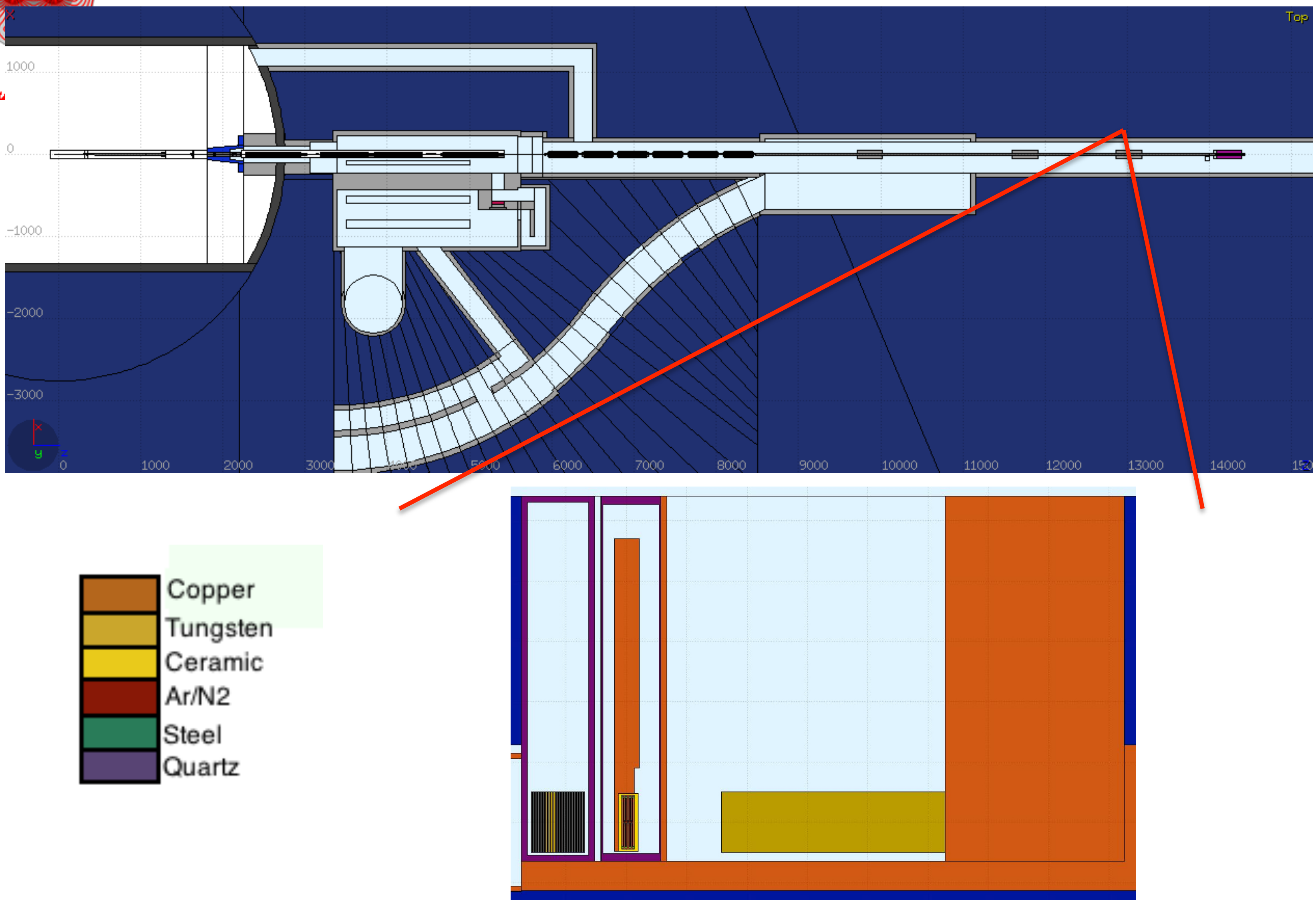


•TAN Model developed by LBL
•2011 Version

ATLAS ZDC

BRAN

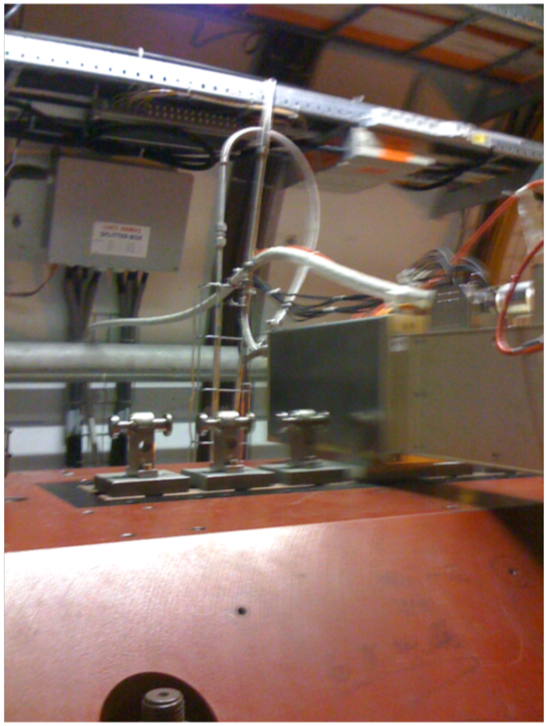
FLUKA model of CMS IP5

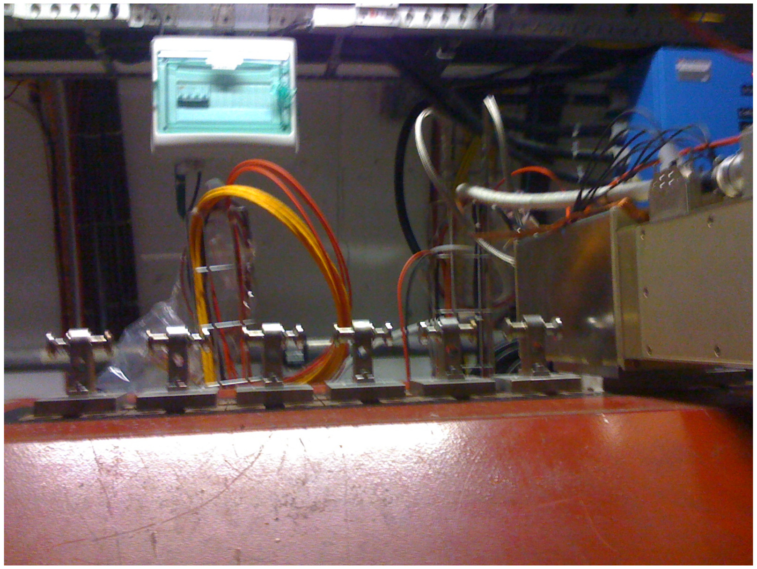


ZDC Detector BRAN

ATLAS Configuration

TAN with absorbers – no ZDCs or LHCf



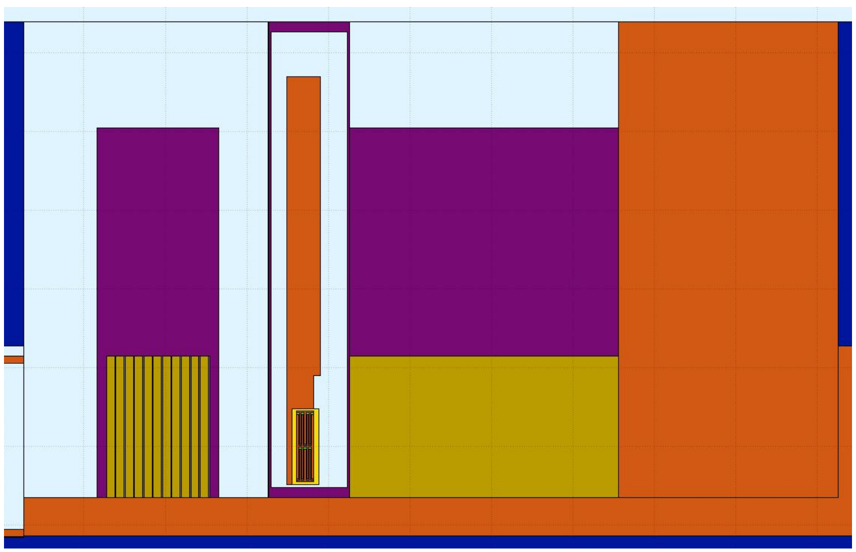


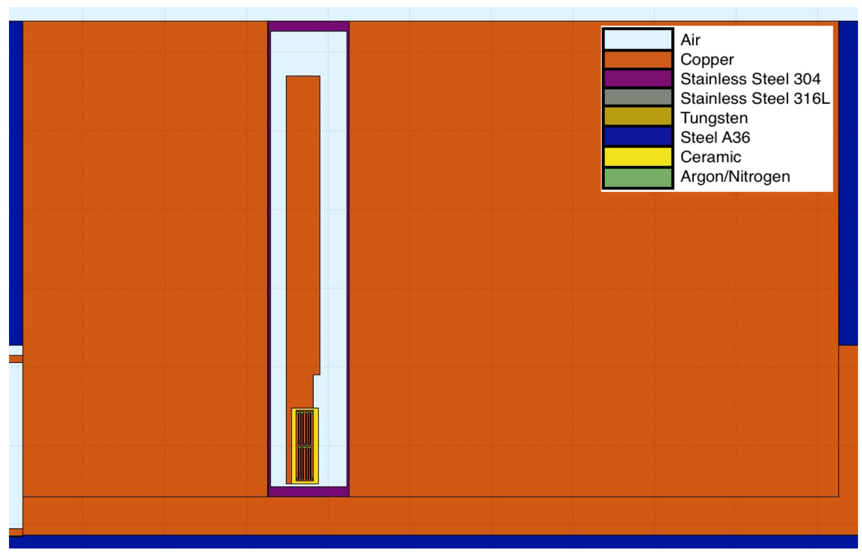
Updating to Higher Lumi Configuration (2012+)

LARP

ATLAS 2011

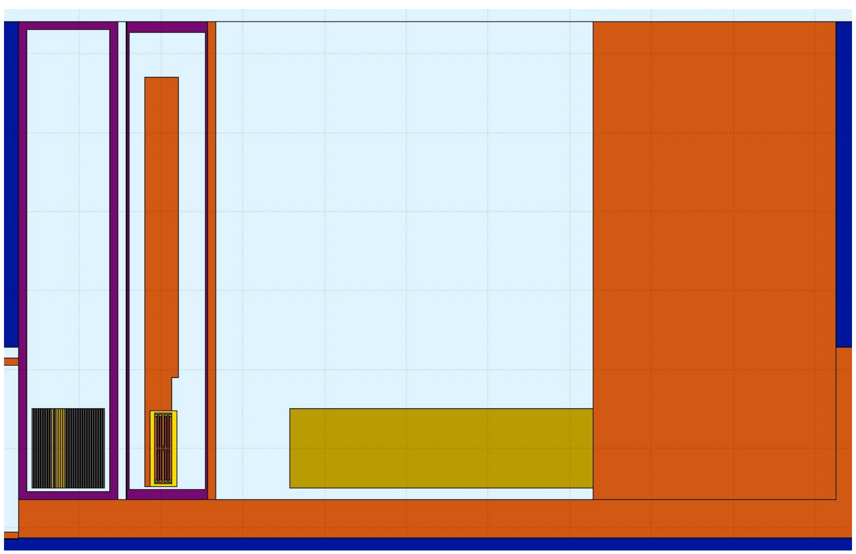
ATLAS 2012



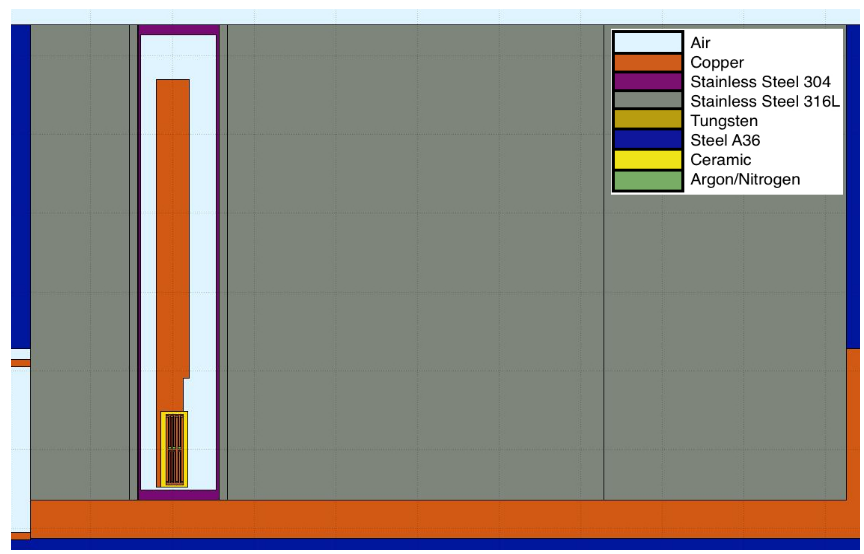


CMS Update

CMS 2011



CMS 2012



How we do simulations

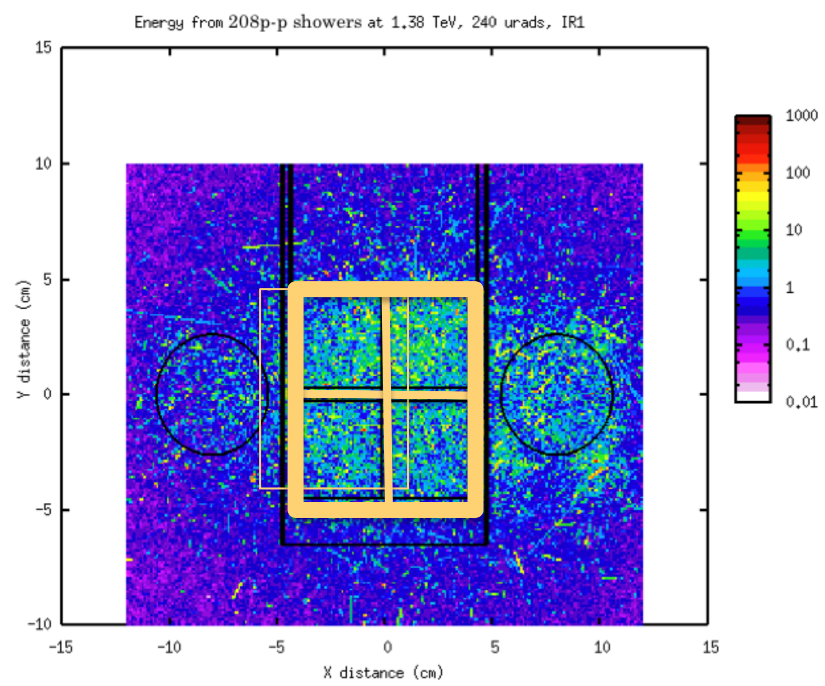
Use geometry for ATLAS and CMS

Collide beams in the center of IR

Transport fragments through the Experimental Magnets and focusing dipoles to the TAN

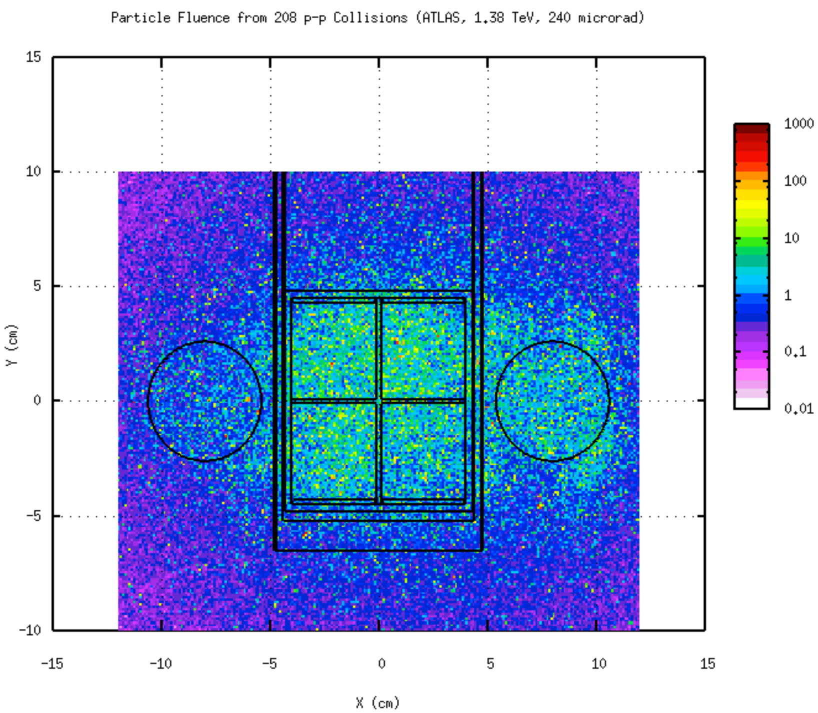
Measure ionization deposited in the TAN/interacting particle

- We can then scale this number to number of interacting collisions/bunch

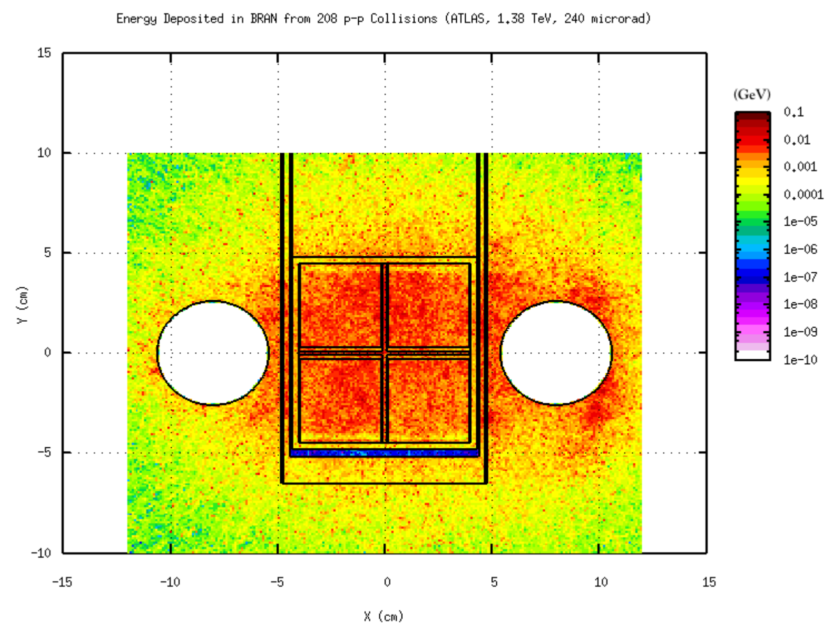


ATLAS Simulation (p-p)

Fluence at BRAN



Energy Deposition at BRAN



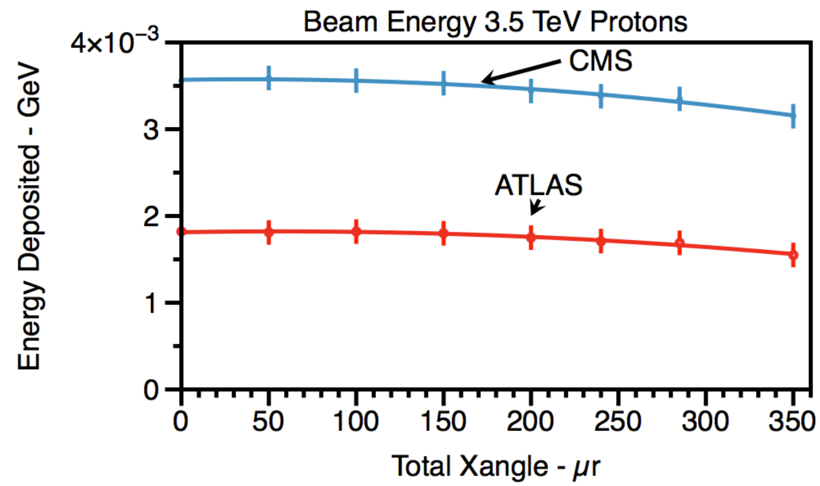
Average Energy Collected/pp interaction

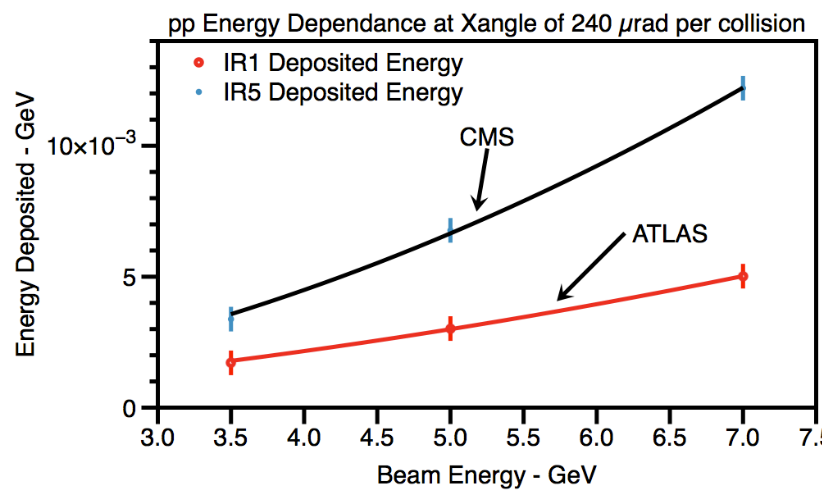
Difference of energy between ATLAS and CMS due to different absorbers

Total energy deposited decreases with increasing crossing angle
- Missing part of the shower

Mapped energy response from 3.5 to 7.0 TeV beam energy with varying crossing angle
- Plot at 240 μrad

If BRAN starts to saturate with increased intensity or luminosity
- can lower pressure and/or
- add attenuators.





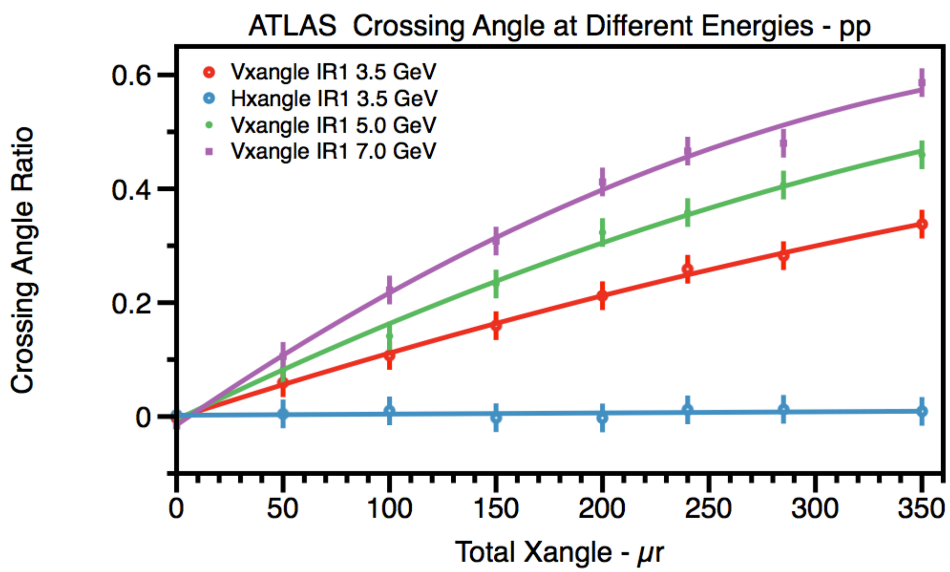
Crossing Angle Asymmetry

Define Crossing angle asymmetry ratio as

$$X_H = \frac{(E_{top} - E_{bottom})}{E_{top} + E_{bottom}}$$

BRAN is sensitive to the crossing angle OF THE MACHINE

Ratio becomes steeper as energy of LHC increases



Recent Model Improvements

Imported the Fluka geometry of IP1 and IP5

- Developed at CERN (ATS-note-2010-046)
- Models from IP to past the TAN

Implemented and configured Fluka 2011 release

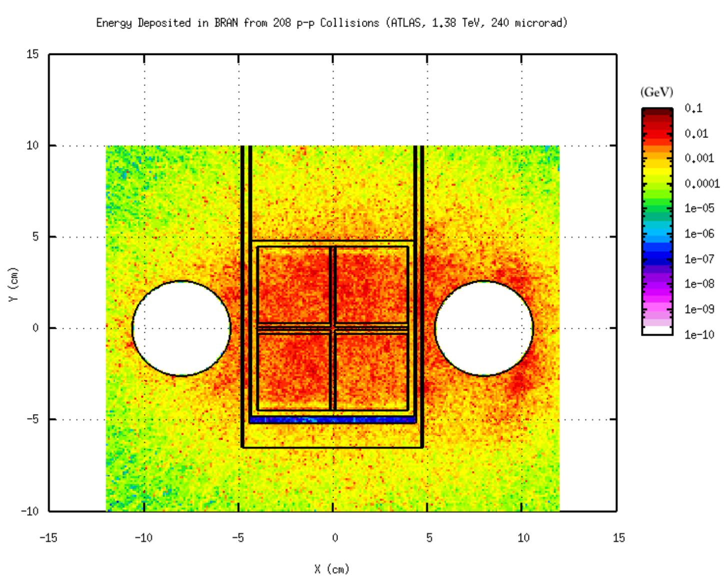
Modified models of detectors at ATLAS and CMS for high luminosity configuration

Ongoing work:

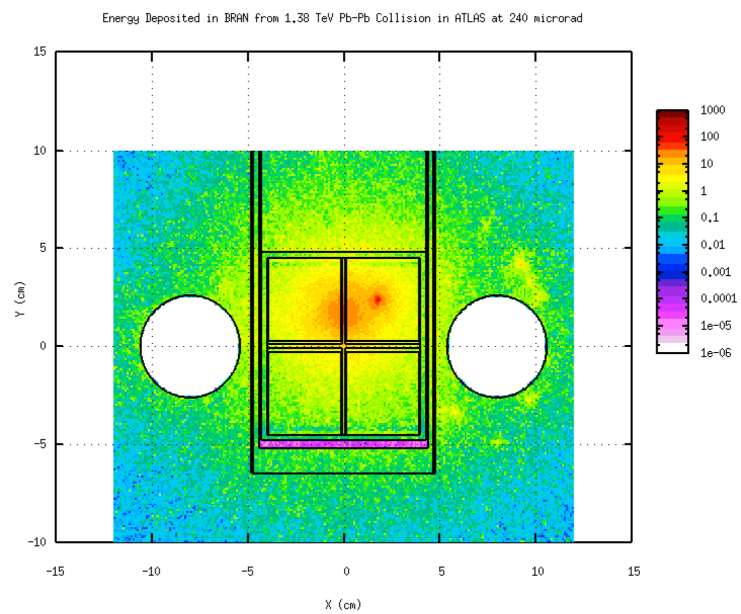
- Heavy Ion Collisions - Demanding CPU requirements
- New regime of physics for FLUKA
  - In collaboration with FLUKA group at CERN

Detector response to Ion Collisions

208 pp collisions



1 Pb collision



Asymmetric Collisions for 2012

LARP

Very Preliminary results

LHC will be running p-Pb collisions later this year

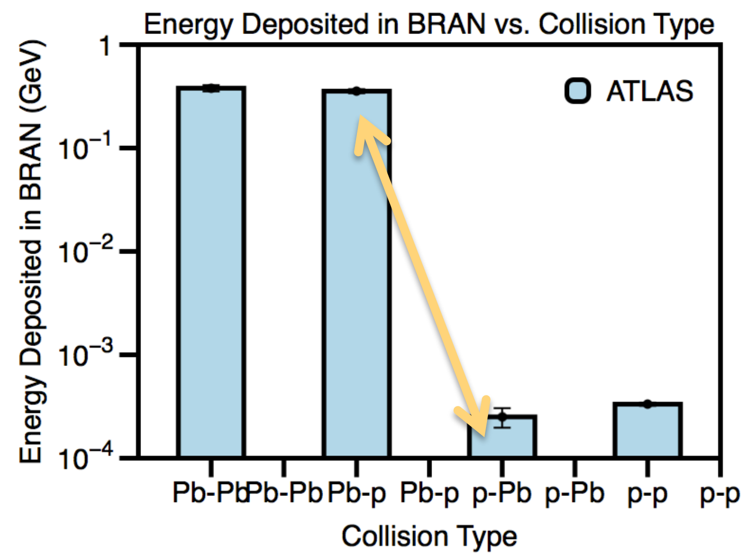
Define p-Pb as p beam heading toward to the BRAN

Pb-p as Pb heading toward the BRAN

Results show that there will be a 10^3 asymmetry for left and right side

Depending on the luminosity probably will only be able to use one of the BRANs/IP

ATLAS at 1.38 TeV/A



Ongoing Activities

Goals for the summer student:

Integrate latest models of the IP from CERN

Run simulations for 2012 data configuration

Compare PbPb and pp results

Also in progress:

Development and implementation of histograms in the DAQ

Monitoring of each detector C vs PH modes during operations

And:

test deconvolution algorithms during 25 ns collisions – if possible during MDs

Lumi Summary

Continue to develop the instrument as the LHC performance increases
- FLUKA modeling
- Analog and DSP performance monitoring and improvements

Participated in v d M scans + lumi calibration runs
- good agreement with experiments

Operator panel with powerful tools
- emittance growth monitoring during the store

Incremental improvements to the system
- software and firmware for diagnostics and calibration

LARP

Final Considerations

All LARP systems are functioning well
- Possible improvements identified and implemented or under study

Developing instruments as the LHC performance increases

Toohig support completed as fellows ‘graduated’
- more challenging to contribute remotely
- contributions more limited to funded activities

Open to shifting on instrumentation of injectors from Linac 4 to the SPS
- and to help with HL-LHC instrument needs

Conclusions

LARP

Spending roughly $7.1M of the ~$80M spent by LARP to date, the instrumentation program has delivered tangible contributions that will help the LHC
- reach design energy
- reach design luminosity

The most direct impact on the LHC from LARP activities so far

Made possible by collaborations with CERN and contributions of each of the LARP labs

New proposals keep facing budgets limitations and competing priorities